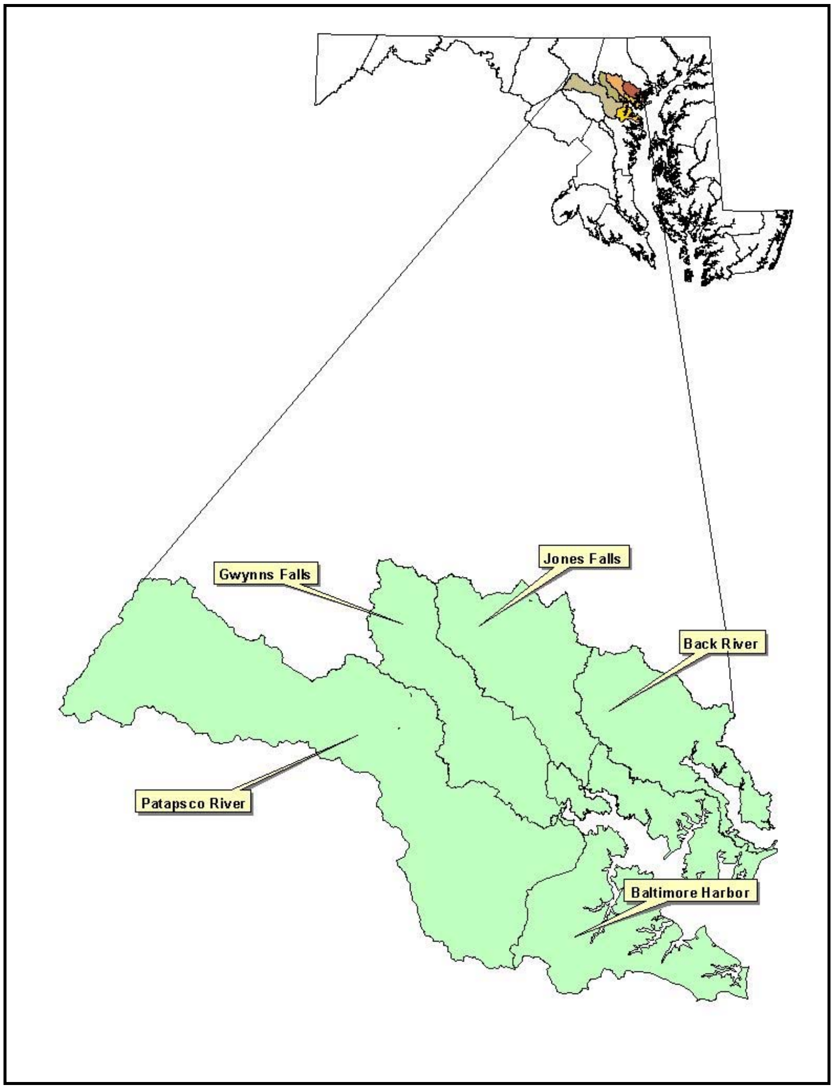
Patapsco / Back River

Watershed SWMM Model Report



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1 Introduction

This report provides a summary on the development and calibration of a watershed model for the Patapsco/Back River Watershed using the Storm Water Management Model (SWMM) Program. A Baltimore Harbor Toxics Total Maximum Daily Load (TMDL) project is currently being developed which will require linkage of the Patapsco/Back River Watershed Model with a Baltimore Harbor Estuarine Hydrodynamic and Water Quality Model. The report includes sections on Watershed Characteristics, Model Structure & Development and Model Calibration and Results.

2 Patapsco/Back River Watershed Characteristics

2.1 Basin Description

The Patapsco Back River Watershed is located in the Upper Western Shore region of the Chesapeake Bay Watershed within Maryland. The Watershed covers portions of Baltimore, Carroll, Howard, Fredrick, Anne Arundel counties and the entire city of Baltimore. The Watershed area contains 524 square miles excluding land areas above the Liberty Reservoir, with 480 square miles contributed by land area and 44 square miles by open water in the Back River and Baltimore Harbor estuaries. The Patapsco/Back River Watershed contains five sub-watersheds: Back River, Jones Falls, Gwynns Falls, Patapsco River and the Baltimore Harbor. Based on scale, watersheds within the state of Maryland are designated by a code system developed by DNR. The codes assigned to the sub-watersheds within the Patapsco/Back River watershed are listed in Table 2.1-1.

Table 2.1-1: Patapsco/Back River 8-digit Sub-Watersheds

Sub-Watershed	MD 8-digit Code	Area (acres)
Back River	02130901	35623
Gwynns Falls	02130905	40329
Jones Falls	02130904	37700
Baltimore Harbor	02130903, 02130902	62499
Patpasco River	02130906, 02130908	130634

For the Patapsco/Back River watershed see Figure 2.1-1.

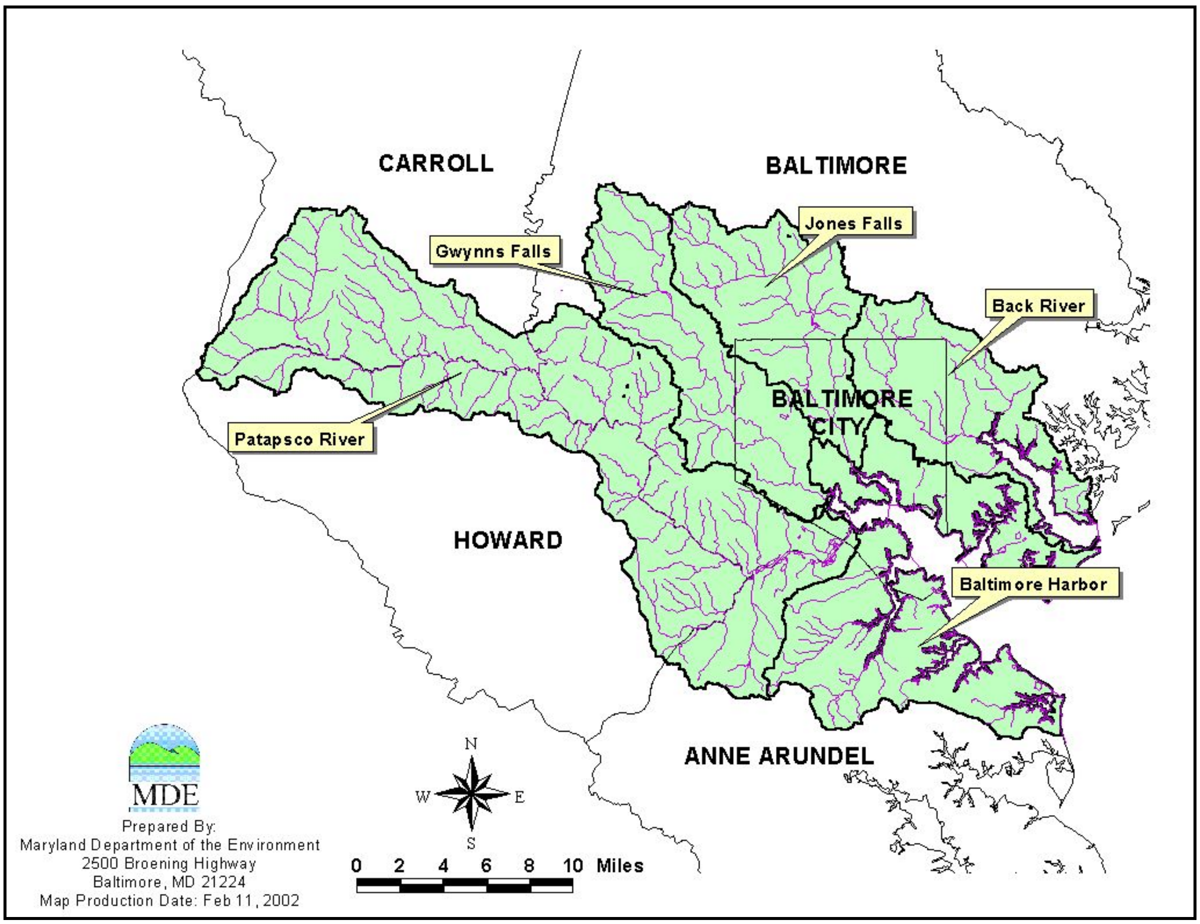

Figure 2.1-1: Patapsco/Back River Watershed

The Jones Falls, Gwynns Falls and Patapsco River Watershed tributaries discharge into the Baltimore Harbor estuary and the Back River tributary discharges into the Back River estuary.

2.2 Climate

The climate of the region is humid, continental with four distinct seasons modified by the close proximity of the Chesapeake Bay. The prevailing direction of storms is from the west-northwest from November through April and the south from May through September. The fall, winter and early spring storms tend to be of longer duration and lesser intensity than the summer storms. During the summer, convection storms often occur during the late afternoon and early evening producing scattered high-intensity storm cells that may produce significant amounts of rain in a short time span. Based on National Weather Service (NWS) data, thunderstorms occur approximately 30 days per year, with the majority occurring from June through August. (SCS, 1976)

2.3 Geology, Topography & Soils

The Patapsco/ Back River watershed lies within the Piedmont and Coastal Plain provinces of Central Maryland. The piedmont province is characterized by gentle to steep rolling topography, low hills and ridges. The surficial geology is characterized by crystalline rocks of volcanic origin consisting primarily of schist and gneiss. These formations are resistant to short-term erosion and often determine the limits of stream bank and stream bed. These crystalline formations decrease in elevation from northwest to southeast and eventually extend beneath the younger sediments of the Coastal Plain. The fall line represents the transition between the Atlantic Coastal Plain Province and the Piedmont Province. The Atlantic Coastal Plain surficial geology is characterized by thick, unconsolidated marine sediments deposited over the crystalline rock of the piedmont province. The deposits include clays, silts, sands and gravels. (Coastal, 1995)

Coverage of the geological formations for the entire Patapsco/Back River watershed is found in Figure 2.3-1. Geologic formations of the individual sub-watersheds are found in Appendix A, Figures 2.3-2 – 2.3-6.

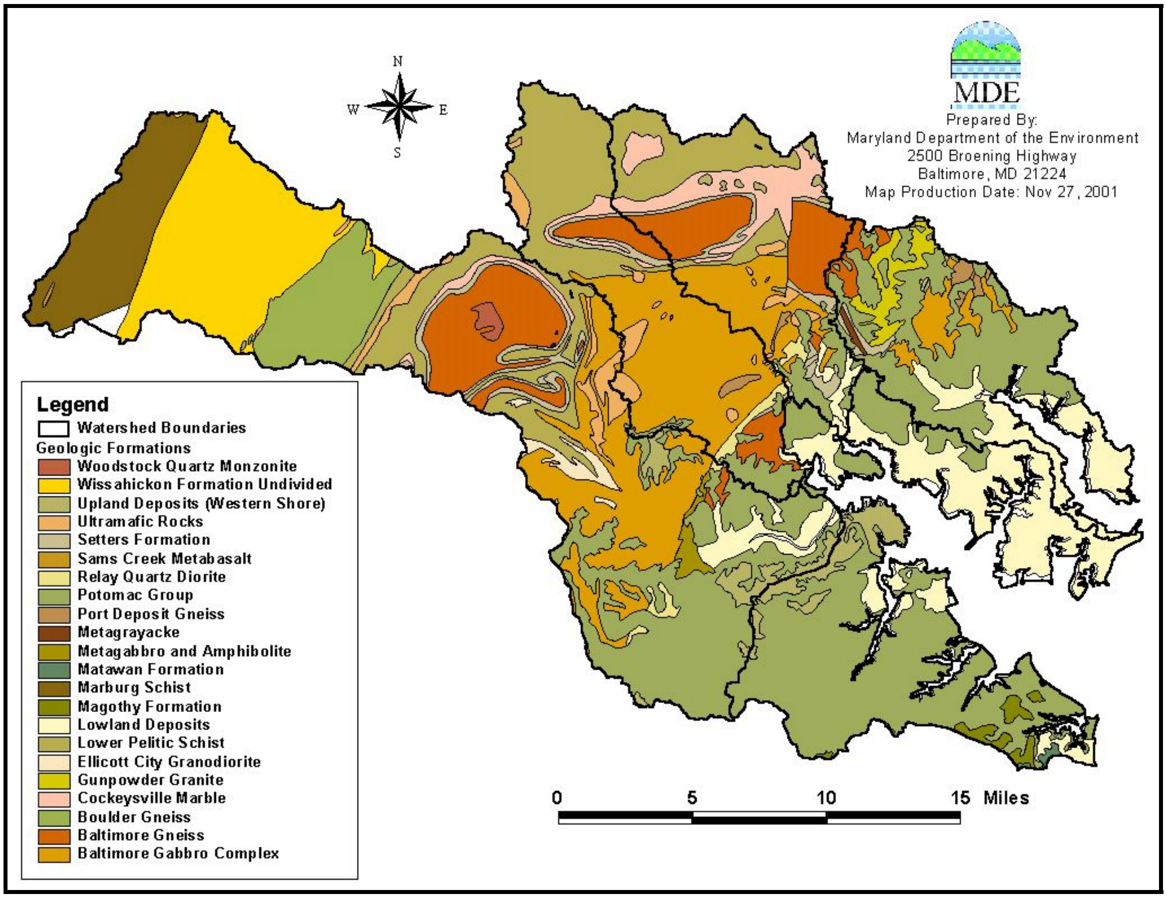

Figure 2.3-1: Patapsco/Back River Geologic Formations

The Patapsco/Back River Watershed is approximately 45 miles long, and drains from northwest to southeast, following the dip of the underlying crystalline bedrock in the Piedmont Province. The surface elevations range from approximately 1,108 feet, near the northwest corner of the study area, to sea level at the Baltimore Harbor and Chesapeake Bay shorelines. Stream channels of the sub-watersheds except for the Baltimore Harbor region are well incised in the Eastern Piedmont, and exhibit relatively straight reaches and sharp bends, reflecting their tendency to following zones of fractured or weathered rock. The stream channels broaden abruptly as they flow down across the Fall line and into the soft, flat Coastal plain sediments. (Coastal, 1995)

3 SWMM Model Description & Structure

A SWMM Model is designed to simulate flow and pollutant loads from a watershed during wet weather periods and pollutant build-up during dry weather periods. Model segmentation is defined by delineating the watershed into smaller sub-watershed areas (model segments) using topographical data. In this project, a SWMM model consisting of multiple catchment segments was developed for each of the five sub-watersheds; Back River, Jones Falls, Gwynns Falls, Patapsco River and Baltimore Harbor.

The watershed is represented within the model by defining various physical hydrologic parameters calculated from land use, soils and topographical data. The hydrologic parameters for each model segment include: segment area, segment width (skew of segment), segment slope, directly connected impervious area (DCIA), minimum/maximum infiltration rate, soil recovery rate, pervious and impervious Manning roughness and pervious and impervious depression storage.

Water quality parameters are defined for build up and wash off of each pollutant and include the following: maximum surface build-up, surface build-up rate and wash-off coefficients. Total Suspended Solids (TSS) generated from surface erosion are calculated from the Universal Soil Loss Equation (USLE) for Barren, Cropland, Pastureland, Forestland and Open Urban land use. The USLE parameters include: rainfall factor, soil erodibility factor, slope length gradient ratio, cropping management/ cover index factor and erosion control practices. All water quality parameters are explained in section 3.10. Calibration of the model is performed using observed flow data for hydrology and locally observed Event Mean Concentration & Unit Load data for water quality. Validation of the water quality calibration was performed by comparing model concentration time series with sampling data.

3.1 Overview of SWMM Model

The Patapsco/Back River SWMM Model uses four of the SWMM model execution blocks. These include RAINFALL, RUNOFF, TRANSPORT and Combine blocks.

The RAINFALL block is used to generate a precipitation time series interface file for use in the RUNOFF block. In addition, rainfall statistics are also reported. Two precipitation gauges are used within the watershed and the simulation was performed from 1/1/92 to 9/31/2001.

The RUNOFF block calculates the edge of stream flow and pollutant load for each model segment. The simulated pollutants are TSS, Cr, Cu, Zn and Pb. The RUNOFF block requires a wet, wet-dry and dry time step. A constant time step of one hour was chosen for computational purposes and consistency among the sub-watershed models and SWMM blocks. Base flow is not calculated by SWMM for this model. A relationship between total rain and surface flow using existing USGS base flow gauge data was developed to estimate base flow for each model segment.

For this model, the TRANSPORT block simulates flow and constituent decay in a stream channel network. A node-channel system is designed where flow from a segment in the runoff block is assigned to a node in the TRANSPORT block. The TRANSPORT block will then route flow of constituents through the stream network (USEPA, 2000). Channel geometries and Manning roughness values are assigned in the model using MDE main channel field-measured data. Overbank stream sections are approximated from 30M USGS DEM data.

3.2 Base Flow Methodology

SWMM was originally designed to simulate urban wet weather runoff but does include a method of estimating base flow (dry weather flow). Continuous flow calibration at the

USGS stream gauge locations was attempted for the Patapsco/Back River watershed model, using SWMM's internal base flow routine. However, model results indicated that the annual flow prediction was reasonable but the monthly and seasonal flow distribution did not calibrate well.

Given the number of USGS gauges in and surrounding the Patapsco/Back River watershed, a more empirical estimate of base flow was developed based on the flow gauge data. A total of ten USGS gauges were selected, of which five were located within the Patapsco/Back River watershed. The gauges are listed in Table 3.2-1 with their corresponding active sampling period dates.

Table 3.2-1: USGS flow gauges used for estimating base flow

USGS Name	Watershed	USGS Gauge #	Drainage Area (sq.mile)	Sampling Period
Western Run at Western Run	Gunpowder	1583500	59.8	1944-present
Long Green Creek at Glen Arm	Gunpowder	1584050	9.4	1975-present
Beaverdam Run at Cockeysville	Gunpowder	1583600	20.9	1982-present
Jones Falls at Sorrento	*Patapsco*	*1589440*	*25.2*	*1997-present*
Gwynns Falls at Villa Nova	*Patapsco*	*1589300*	*32.5*	*1997-present*
Herring Run at Idlewylde	*Patapsco*	*1585200*	*2.13*	*1997-present*
Moores Run near Todd Ave	*Back River*	*1585225*	*0.21*	*1996-present*
Whitemarsh Run near White Marsh	Gunpowder	1585100	7.61	1992-present
North Fork Whitemarsh Run	Gunpowder	1585095	1.34	1992-present
Moores run at Radecke Ave	*Back River*	1585230	3.52	*1996-present*

*Gauges in italics were supplemented with a additional data based on regression to a hydrologically similar gauge.

The gauges located within the Patapsco/Back River watershed were limited in data during the watershed model run period (1/1/1992 to 9/30/2001). Since base flow estimates are needed for the complete watershed model simulation period, missing gauge data were supplemented with observations from a hydrologically similar gauging station. Criteria used for determining a hydrologically similar basin required the evaluation of total runoff and the ratio of surface flow to base flow. Estimates for missing observations were based on non-linear regression techniques used to fit and general equation between the gauge partial time series and the nearby gauge complete time series. The equation is as follows:

$$Q_e = a \cdot (Q_g)^b$$

where

Q_e = estimated daily flow at site

Q_g = gauged daily flow at nearby station

a, b = coeficient

Base flow was estimated using the USGS HYSEP (Soto et. al., 1996) program to separate the gauged streamflow hydrograph. The following three hydrograph separation options are allowed in HYSEP: fixed-interval method, sliding-interval method and local-minimum method. All three methods were evaluated and the fixed-interval method was selected for use in this study. Justification for using the fixed-interval results from SWMM's surface water calculation only simulating runoff with no account for interflow from the unsaturated zone. The fixed interval method was selected because it produced the highest base flow estimate of the three-hydrograph separation options. The final separated base flow was normalized by watershed area and then aggregated into weekly flows for input into the SWMM model. Base flow hydrographs can be found in figure 3.2-1.

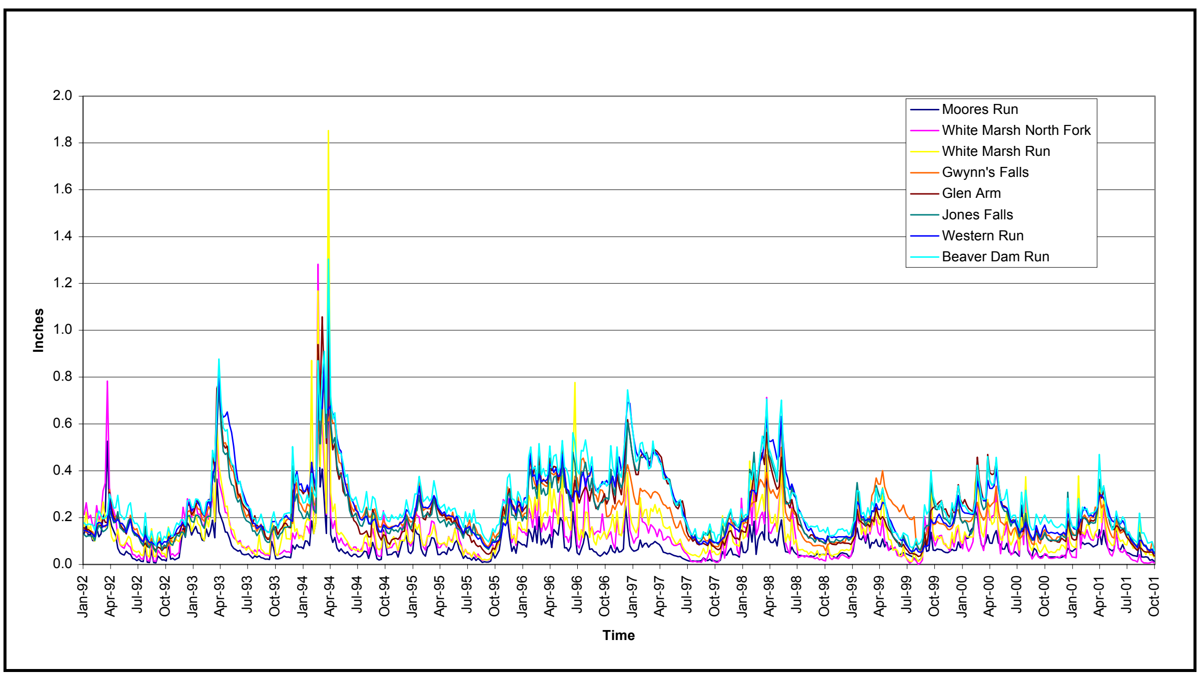

Figure 3.2-1: USGS gauge station weekly base flow (area normalized)

Using the gauged base flow within the SWMM model required developing a relationship between the surface runoff, simulated by SWMM, and the base flow estimates from the gauges. A plot depicting surface runoff vs. base flow is presented in figure 3.2-2. It can be seen that there is an approximate linear correlation between surface runoff and base flow for the selected gauges. Notice that the Moores Run USGS gauges have a linear trend, and similar slope to other gauges, however the y-intercept is much less, this indicates much less base flow for a given surface runoff. After speaking with the City of Baltimore about this (Stack, 2002), they assumed that the loss of base flow resulted from the urban infrastructure (drainage pipe) constructed below the streambed. The Moores run gauges were thus assumed outliers and not used in the regression.

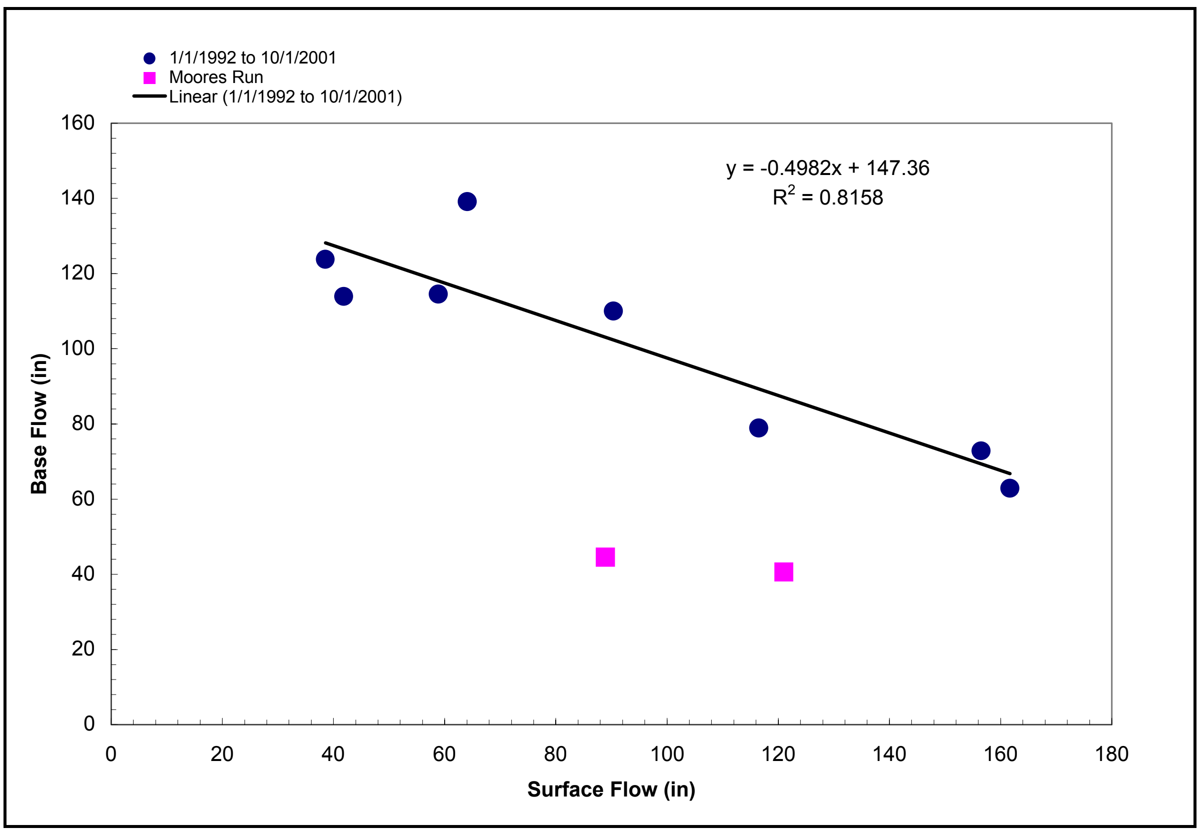

Figure 3.2-2: USGS gauged base flow vs surface flow (area normalized)

Estimation of base flow within the Patapsco/Back River SWMM model used the following equation:

$$\text{Baseflow} = -0.4982 \cdot \text{Surflow} + 147.36$$

Surface flow was generated from the SWMM model and then the total cumulative base flow was estimated from the regression equation shown above. Next, the base flow time series was calculated using a weighted average of the two gauges that produced the most similar cumulative base flow, compared to that of the estimated base flow. This methodology was applied within each model segment and the surface and base flows were combined and then routed using the SWMM TRANSPORT block.

3.3 Existing Model Studies

Four existing SWMM Watershed models have been developed by Baltimore County within the Patapsco/ Back River Watershed. These include the following: Back River, Patapsco River, Baltimore Harbor and Jones Falls watersheds. A SWMM Watershed Study was also developed by Baltimore City for Moores Run within the Back River watershed. For the Jones Falls and Patapsco River watersheds only the areas within Baltimore County are modeled. For the Baltimore Harbor watershed model, Bear Creek and Old Road Bay are modeled. Figure 3.3-1 shows the areas modeled by the Baltimore County and Baltimore City SWMM watershed studies within the Patapsco/Back River watershed.

An HSPF watershed model was also developed by MDE for the Patapsco/Back River watershed. The MDE HSPF model simulates nutrients and TSS export from 1/1/96 to 10/1/98.

The Chesapeake Bay Model developed by the Chesapeake Bay Program (CBP) consists of three segments, two in the Patapsco watershed and one in the Back River watershed. The

CBP model simulates nutrients and TSS export from 1/1/84 to 12/31/97. The CBP segmentation is displayed in Figure 3.3-2. Hydrology and TSS loading results from the HSPF and CBP model have been compared with the SWMM model. A comparison of annual loads from the existing watershed studies is found in Table 3.3-1.

Table 3.3-1: Existing Watershed Studies Annual Loads

Watershed	Source	Area (acre)	Flow (MG)	TSS (tons)	Cu (lbs)	Zn (lbs)	Pb (lbs)
Back River	MDE SWMM (1992 - 2000)	35,623	22,542	3,531	2,960	15,907	2,577
	MDE HSPF (1993 - 1997)	34,785	23,181	2,125			
	Back River Watershed Water Quality Management Plan (Baltimore County, 1996)			3,174	2,595	11,184	3,397
	CBP Version 4.3 (1993 - 1997)	46,851	33,208	7,298			
Back River	MDE SWMM (1999)	2273	1513	241	226	979	166
(Moores Run at Radecke Ave.)	Moores Run Watershed Plan (Baltimore City, 2001)	2323	1055	239	109	985	186
Back River	MDE SWMM (1999)	3194	2154	357	323	1536	261
(Moores Run Watershed)	Moores Run Watershed Plan (Baltimore City, 2001)	3027	1414	449	202	1865	366
Baltimore Harbor	MDE SWMM (1992 - 2000)	271,162	158,865	41,086			
	MDE HSPF (1993 - 1997)	266,888	179,242	24,651			
	CBP Version 4.3 (1993 - 1997)	255,952	142,209	89,407			
Upper Jones Falls	MDE SWMM (1992 - 2000)	16,946		2570	638	3341	535
	Jones Falls Watershed Water Quality Management Plan (Baltimore County, 1997) Sub-watersheds 1,2,3,4 & 8 year 1982	16,947		1,114	329	1,505	634
Baltimore Harbor	MDE SWMM (1992-2000)	9,684		707	567	3946	638
(Bear Creek & Old Road Bay)	Baltimore Harbor Watershed Water Quality Management Plan (Baltimore, County, 2000)	9,766		490	423	4,242	1,793

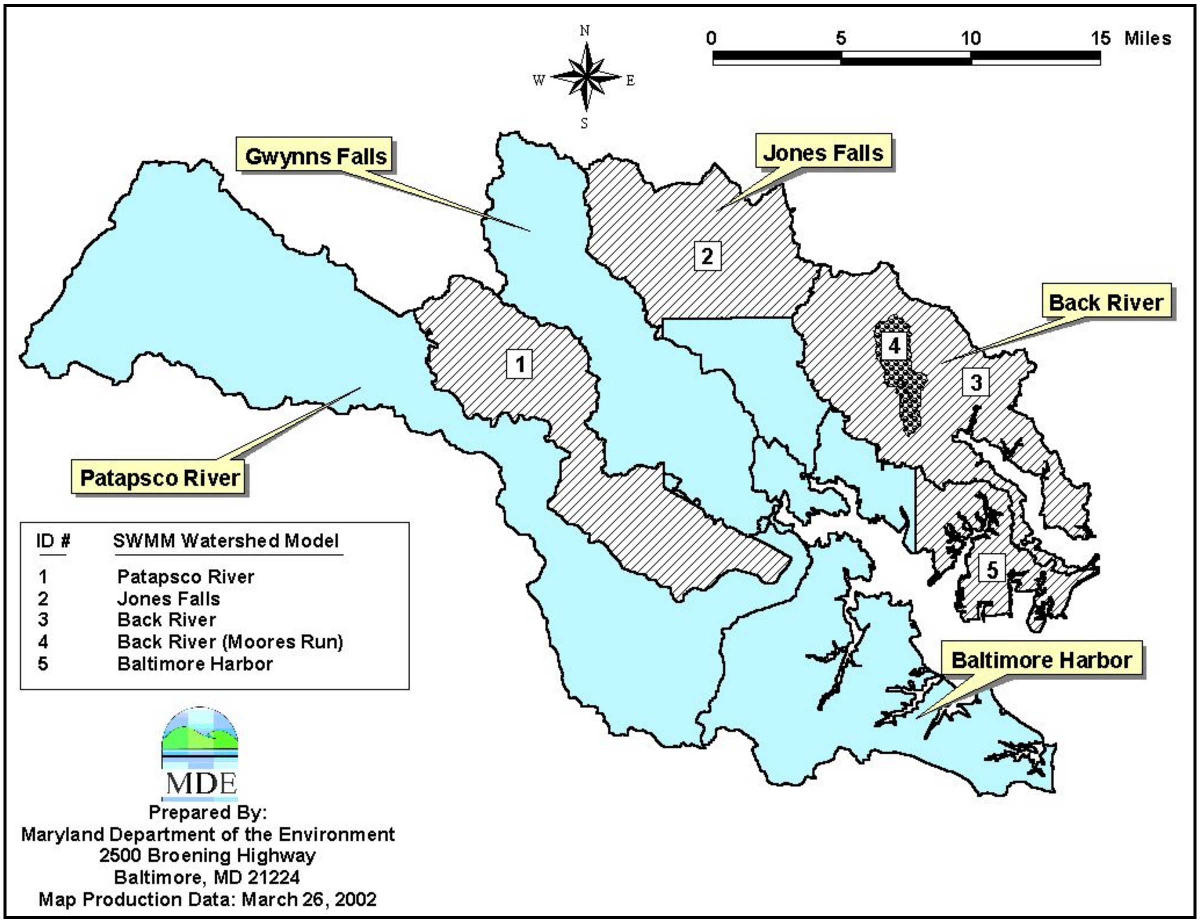

Figure 3.3-1: Existing Watershed Model Study Areas

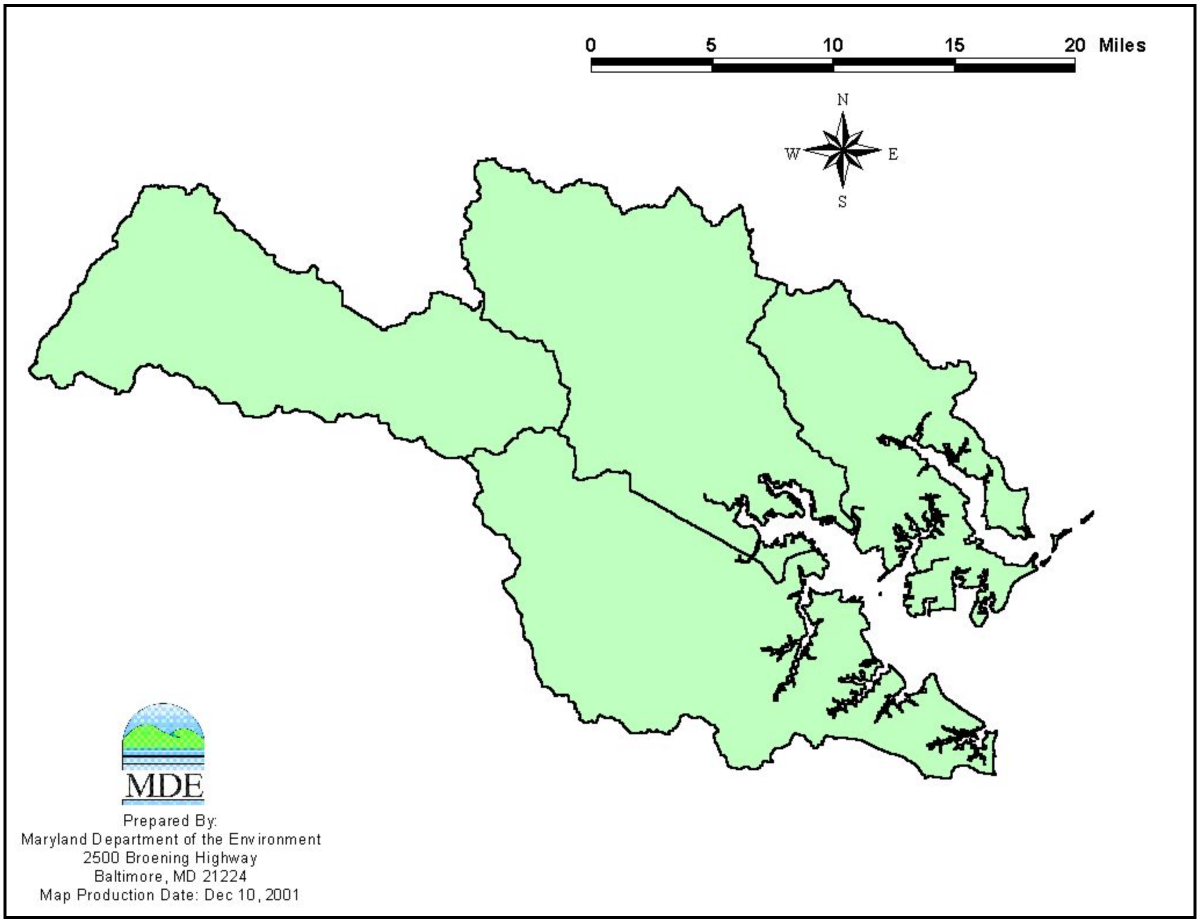

Figure 3.3-2: Patapsco/Back River CBP Model Segmentation

3.4 SWMM Model Segmentation

The Patapsco/Back River watershed segmentation was created using the MDE 12-digit watersheds, incorporating existing Baltimore County model segmentation and using USGS topographical quad maps to delineate segment boundaries with USGS gauge locations. Baltimore County SWMM Model Segmentation exists for portions of Back River, Jones Falls, and Patapsco River on a fine resolution. Baltimore County's Jones Falls model segmentation was similar to the Maryland 12-digit code, requiring no aggregation. Baltimore County's Patapsco River model segmentation was aggregated to the 12-digit watershed scale to reduce the size of the model. Baltimore County's Back River model segmentation was aggregated using the Baltimore County's sub-watersheds. The Back River segmentation is finer when compared to the segmentation used in the Patapsco River watershed. Using Baltimore County sub-watersheds resulted in finer resolution segmentation when compared to the Patapsco River watershed segmentation. Fine scale models were not required for the scope of this project. To obtain the required resolution for this project the watershed was delineated to the Maryland 12 digit watershed to include significant USGS gauges.

The purpose of the model developed in this project is to simulate flows and loads delivered to the Baltimore Harbor and Back River Estuaries. The SWMM model segmentation for the Patapsco/Back River watershed is shown in Figure 3.4-1.

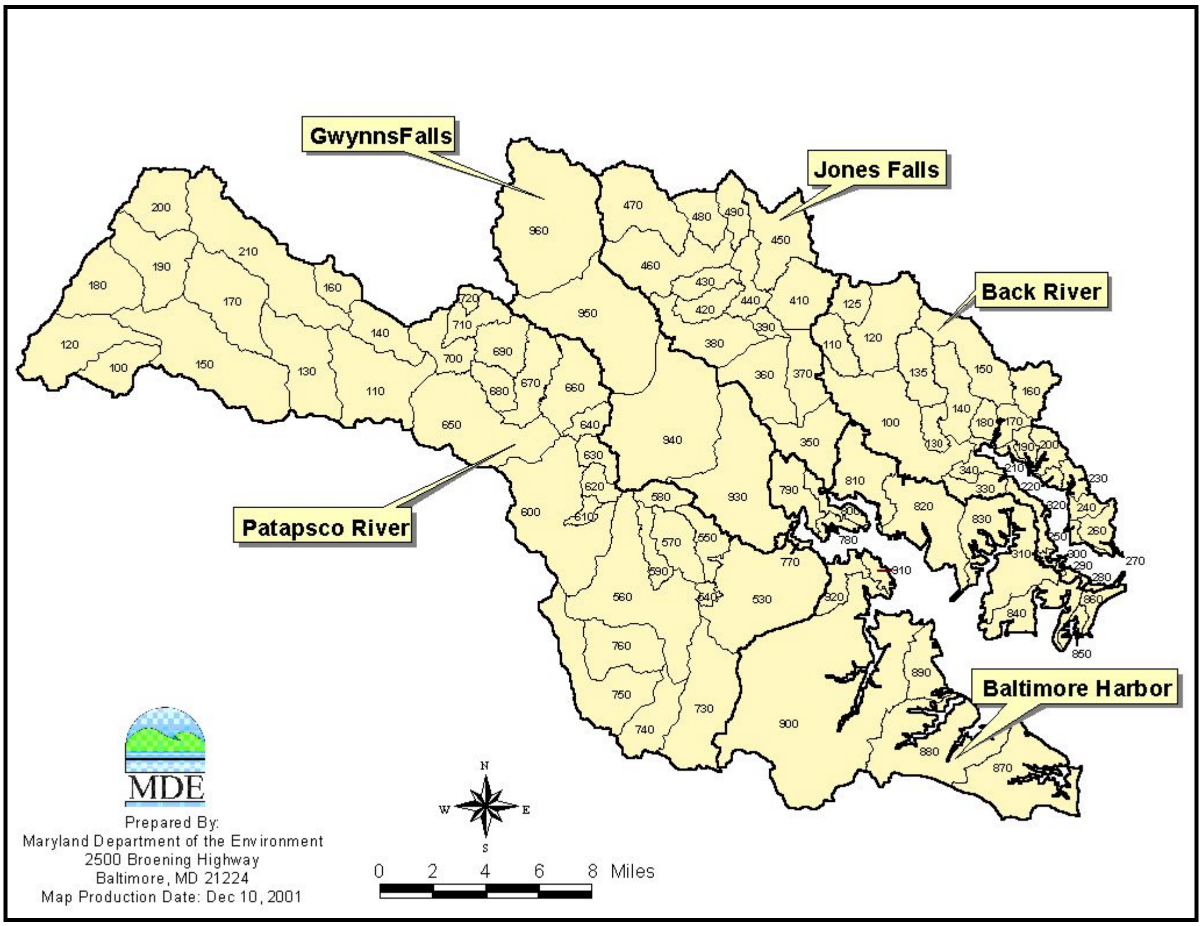

Figure 3.4-1: Patapsco/Back River SWMM Model Segmentation

3.5 Land Use

The SWMM model requires input of land use percentages for each segment to define hydrology and pollutant loads. Land use data was obtained from the 1997 Maryland Office of Planning Land GIS coverage. The coverage contains 22 different land use classifications, which were than aggregated down to ten model categories. The aggregated land use groups for the SWMM model are listed in Table 3.5-1.

Table 3.5-1: SWMM Land Use Groups

SWMM Land Use Group	Land Use Code	Land Use Classification
Commercial/Industrial	14	Commercial
	15	Industrial
High Density Residential	13	High Density Residential
Medium Density Residential	12	Medium Density Residential
	16	Institutional
Low Density Residential	11	Low Density Residential
Water	50	Water
	60	Wetlands
Open Urban Land	17	Extractive
	18	Open Urban Land
Cropland	21	Cropland
	23	Orchards/Vineyards/Horticulture
	25	Row and Garden Crops
Pastureland	22	Pasture
	24	Feeding Operations
Forestland	41	Deciduous Forest
	42	Evergreen Forest
	43	Mixed Forest
	44	Brush
Barren	71	Beaches
	72	Bare Exposed Rock
	73	Bare Ground

The land use coverage for the Patapsco/Back River watershed is displayed in Figure 3.4-1. Land use coverage for each sub-watershed is displayed in Figures 3.5-2 to 3.5-6 in Appendix C.

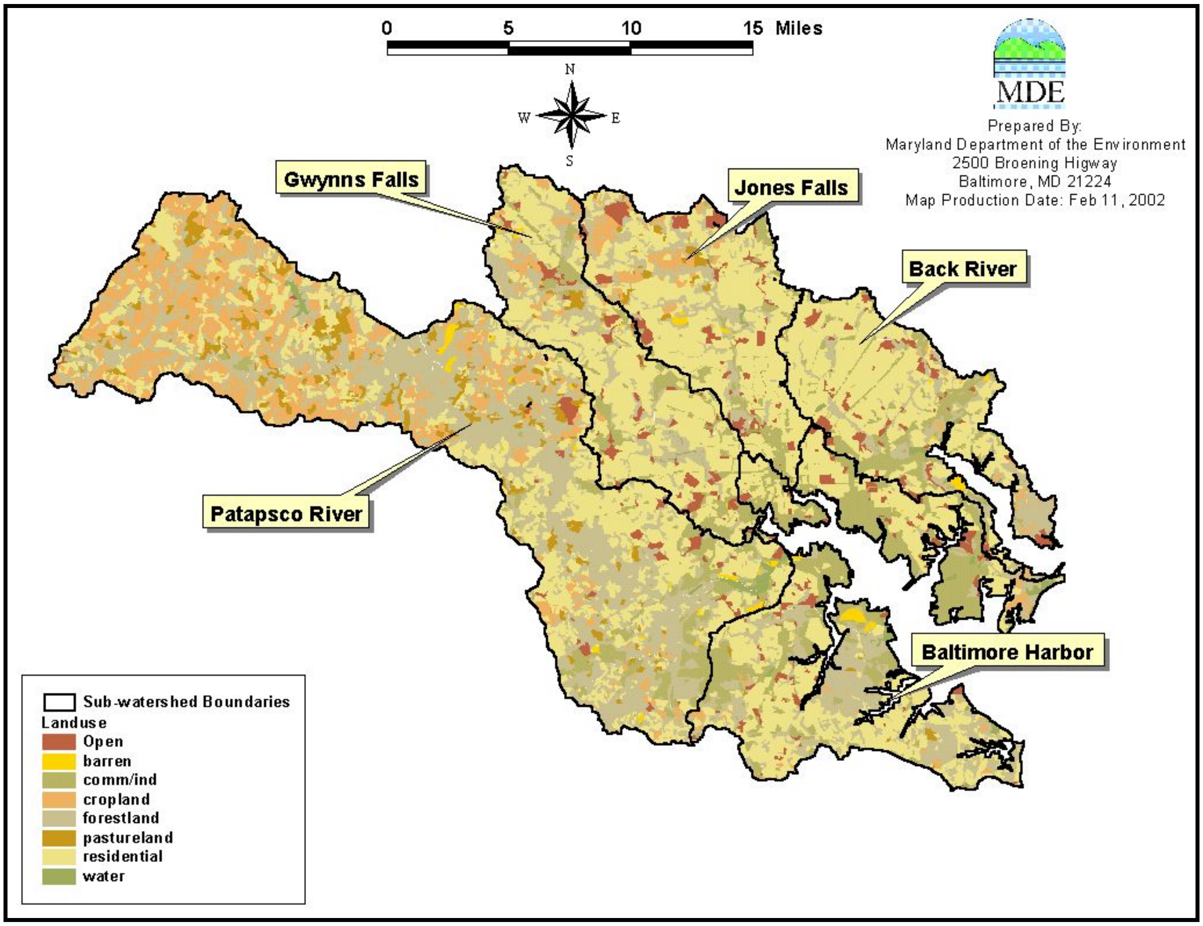

Figure 3.5-1-Patapsco/Back River Watershed Land Use Coverage

A summary of land use percentages for each sub-watershed is given in Table 3.5-2. Urban land uses (Commercial/Industrial, High, Medium and Low Density Residential) account for over 53% of the total Patapsco/Back River Watershed. Forestland also accounts for over 26% of the total watershed area. The land use percentages for each sub-watershed segment are given in Tables 3.5-3 to 3.5-7 in Appendix D.

Table 3.5-2: Patapsco/Back River Watershed Land Use Percentage

Land Use	Back River	Gwynns Falls	Jones Falls	Baltimore Harbor	Patpasco River	Total
Comm/Ind	15.5%	14.0%	7.8%	26.3%	6.1%	12.6%
Hdr	16.7%	16.5%	11.9%	12.0%	2.8%	9.2%
Mdr	37.6%	33.9%	23.8%	23.8%	11.4%	21.5%
Ldr	2.0%	4.8%	21.8%	5.0%	13.4%	10.3%
Water	1.9%	0.5%	0.4%	4.6%	0.8%	1.6%
Open	6.6%	5.8%	7.4%	4.5%	1.3%	3.9%
Cropland	1.8%	3.8%	6.9%	1.8%	20.4%	10.6%
Pastureland	0.0%	1.0%	2.1%	0.2%	6.0%	3.0%
Forestland	17.3%	19.3%	17.5%	21.1%	37.1%	26.8%
Barren	0.6%	0.3%	0.5%	0.6%	0.7%	0.6%

3.6 Meteorological Data (Precipitation & Evaporation)

Precipitation Data was obtained from two NWS gauges, station 0180465 located at Baltimore/Washington International Airport (BWI) and station 0181862, located in Clarksville, Md in Howard County. The rainfall intensity time series is based on an hourly record and assigned in the RAINFALL block of the SWMM model. The period of record for the gauge stations 0180465 and 01801862 is 6/1/1950 to present and 1/1/1958 to present, respectively. The BWI gauge rainfall series is used alone in the sub-watersheds models except for the Patapsco River. The Clarksville and BWI gauge rainfall series are used in the Patapsco River watershed model in order to more realistically capture the rainfall events that occur, thus improving the hydrology calibration. The rainfall time series are assigned to the appropriate segment by finding the bisection of the gauges and overlaying this line with the segmentation to determine what side of the line each segment falls.

Locations of the rain gauges within the Patapsco/Back River watershed are displayed in Figure 3.6-1.

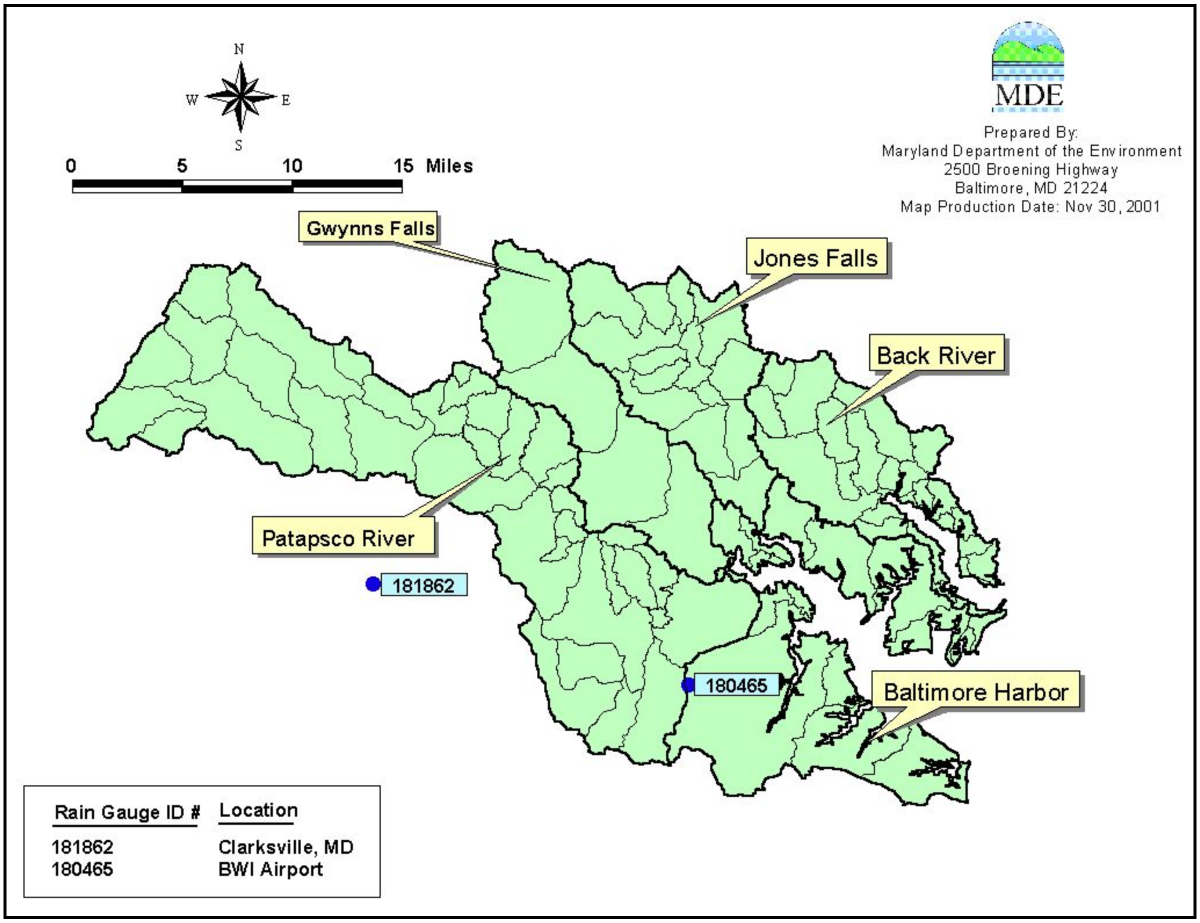

Figure 3.6-1: Patapsco/ Back River Watershed Rain Gauge Locations

Evaporation data was obtained from the CBP and assigned as monthly values for the entire model simulation period of 1/1/92 to 9/30/01. The CBP program data ended in 12/31/1999. Monthly values from 1999 were applied in years 2000 & 2001.

3.7 Soils Data

Soil Percentages of each soil group for each model segment are calculated using a GIS soil coverage developed from the following data sources: Baltimore City (SSURGO), Baltimore County, and Ragan (Ragan, 1991) for Anne Arrundel, Carroll, and Howard Counties. The soil data is categorized by four hydrologic soil groups developed by the Soil Conservation Service (SCS). The definitions of the groups are as follows (SCS, 1976):

A: Soils with high infiltration rates, typically deep well-drained to excessively drained sands or gravels.

B: Soils with moderate infiltration rates, generally moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

C: Soils with slow infiltration rates, mainly soils with a layer that impedes downward water movement or soils with moderately fine to fine texture.

D: Soils with very slow infiltration rates, mainly clay soils, soils with a permanently high water table, and shallow soils over nearly impervious material.

The distribution of soils within the Patapsco/Back River Watershed is displayed in Table 3.7-1 below.

Table 3.7-1: Patapsco/Back River Watershed Soil-Type Percentages

Sub-Watershed	Back River	Jones Falls	Gwynns Falls	Patapsco River	Baltimore Harbor
A	1.6%	1.2%	0.2%	11.0%	9.1%
B	38.2%	65.9%	49.3%	49.7%	16.1%
C	38.7%	14.8%	24.1%	27.6%	27.3%
D	21.5%	18.1%	26.4%	11.7%	47.5%

The Patapsco/Back River watershed is mainly comprised of B type soils except for the Baltimore Harbor watershed in which mostly D type soils exist. This is in part due to the SSURRGO soil coverage classifying the soil as urban. Given the compaction that occurs with development, urban soils within the SSURGO coverage are assigned the D soil type. The soil percentages for each model segment in the five sub-watersheds are found in Tables 3.7-2 to 3.7-6 in Appendix E.

3.8 Calibration Data (Hydrology & Water Quality)

3.8.1 USGS Flow Data

USGS flow gauge data is used to calibrate the SWMM model hydrology. A total of seven USGS flow gauges were used for model calibration and validation. Three flow gauge stations within the Patapsco Watershed and two stations within the Back River Watershed are used to calibrate the stream flow. Due to the limited amount of observed data at the downstream gauge stations (Jones Falls at Washington Blvd and Gwynns Falls at Maryland Ave) they are used to validate the calibration. All USGS flow gauges have not been under continuous operation during the entire model study period. Table 3.8.1-1 lists the gauge and period of observation during the SWMM simulation.

Table 3.8.1-1: Patapsco/Back River Watershed USGS Flow Gauges

Model	Flow Station	Begin Date	End Date	Model Usage
SWMM	Gwynns Falls at Villa Nova	10/01/1996	09/30/2001	Calibration
SWMM	Jones Falls at Sorrento	10/01/1996	09/30/2001	Calibration
SWMM	Patapsco River at Hollofield	03/31/1994	09/30/1995	Calibration
SWMM	Patapsco River at Hollofield	01/01/2000	09/30/2001	Calibration
SWMM	Back River at Herring Run	01/01/1997	09/30/2001	Calibration
SWMM	Back River at Moores Run	07/23/1996	09/30/2001	Calibration
SWMM	Gwynns Falls at Washington Ave.	10/01/1998	09/30/2001	Validation
SWMM	Jones Falls at Maryland Ave.	10/27/1999	09/30/2001	Validation

The USGS flow gauge station locations within the Patapsco/Back River watershed are displayed in Figure 3.8.1-1. The gauge locations within each sub-watershed are found in Figures 3.8.1-2 to 3.8.1-5 in Appendix F.

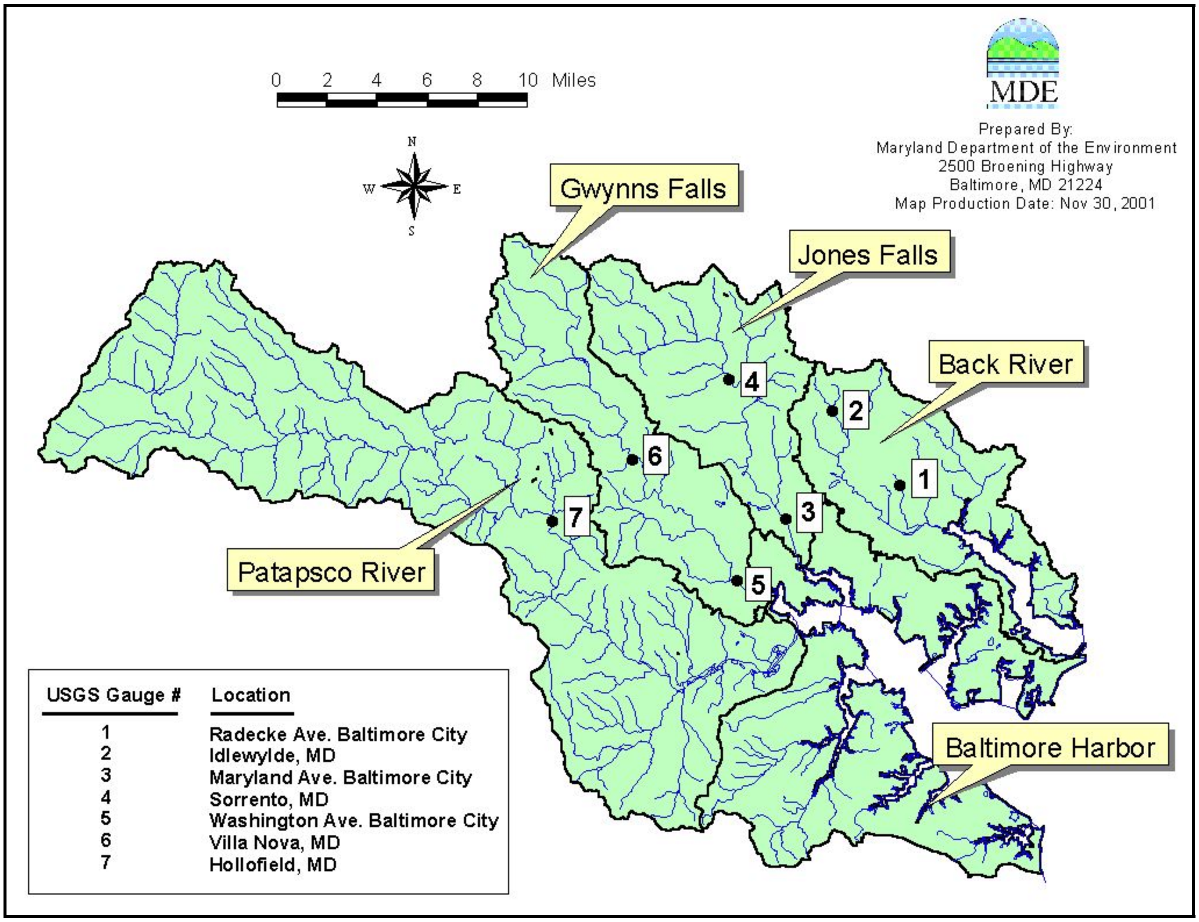

Figure 3.8.1-1: Patapsco/Back River Watershed USGS Flow Gauge Locations

3.8.2 Liberty Reservoir Flow Data

The Liberty Reservoir is located within the Patapsco River Watershed. The land area above the reservoir is excluded from the Patapsco River SWMM model. Monitored dam elevation data from the reservoir was obtained from Baltimore City. Daily reservoir elevations are reported from 1/1/1992 to 7/1/2000. When the reservoir elevations exceed the dam elevation the weir equation is used to calculate the volumetric overflow rate. A daily flow (cfs) time series was created and input into the model. The weir equation is as follows:

$Q = C_W \times L_W(h-h_o)^{3/2}$

Q = flow (ft^3/s)
C_W = 3.3 (ft/s)
L_W = Dam Width = 480 (ft)
h = Water Elevation
h_o = Dam Elevation = 420 (ft)

No pollutant loads were input into the model from the reservoir because it is assumed that the liberty reservoir acts as a trap for the pollutants simulated (TSS, Cr, Cu, Pb & Zn) preventing them from being carried in the overflow. Table 3.8.2-1 shows the year and number of days in which overflow occurs.

Table 3.8.2-1: Liberty Reservoir Overflow Data

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Days of Overflow	0	68	107	0	231	115	82	0	0	0

3.8.3 Stream Water Quality Data

Stream water quality time series data within the Patapsco/Back River Watershed was obtained from Baltimore City. Table 3.8.3-1 lists the sample location, pollutant sampled, period of sampling and number of samples. Downstream locations are found near the entrance to the Baltimore Harbor. Figure 3.8.3-1 shows the location of the sampling sites within the Back River Watershed. A comparison of model and observed concentration values is made in order to validate the water quality calibration. Water quality data for TSS was available from DNR for the Patapsco River, Jones Falls, and Gwynns Falls upstream USGS gauge stations. However most of the data was obtained during dry weather flow and thus not applicable since TSS tends to be storm event driven.

Table 3.8.3-1: Baltimore City Sampling Site Information

Watershed	Station ID	Station Location	Constituent	Sampling Period	# Samples
Jones Falls	240	Sorrento USGS Gauge	TSS	1/9/97 - 12/23/97	65
Jones Falls	241	Downstream	TSS	1/9/97 - 12/23/97	59
Jones Falls	241	Donwstream	Cu/Pb/Zn	6/17/97 - 6/12/98	62
Gwynns Falls	230	Villa Nova USGS Gauge	TSS	1/9/97 - 12/23/97	58
Gwynns Falls	231	Downstream	TSS	1/9/97 - 12/23/97	70
Gwynns Falls	231	Downstream	Cu/Pb/Zn	6/17/97 - 6/12/98	78
Patapsco River	211	Hollofield USGS Gauge	Cu/Pb/Zn	6/17/97 - 6/12/98	61
Back River	250	Herring Run USGS Gauge	TSS	1/9/97 - 12/23/97	55
Back River (Moores Run)	-	Radecke Ave.	Cu/Pb/Zn	2/28/95 - 1/09/01	809
Back River (Moores Run)	-	Radecke Ave.	TSS	2/28/95 - 1/09/01	1231
Back River (Moores Run)	-	Biddle St. & 62nd St.	Cr/Cu/Pb/Zn	6/10/97 - 8/15/00	41
Back River (Chinquapin Run)	-	Hillen Road	Cr/Cu/Pb/Zn	6/9/97 - 8/15/00	37
Back River (Herring Run)	-	Pulaski Highway	Cr/Cu/Pb/Zn	5/14/97 - 8/15/00	40

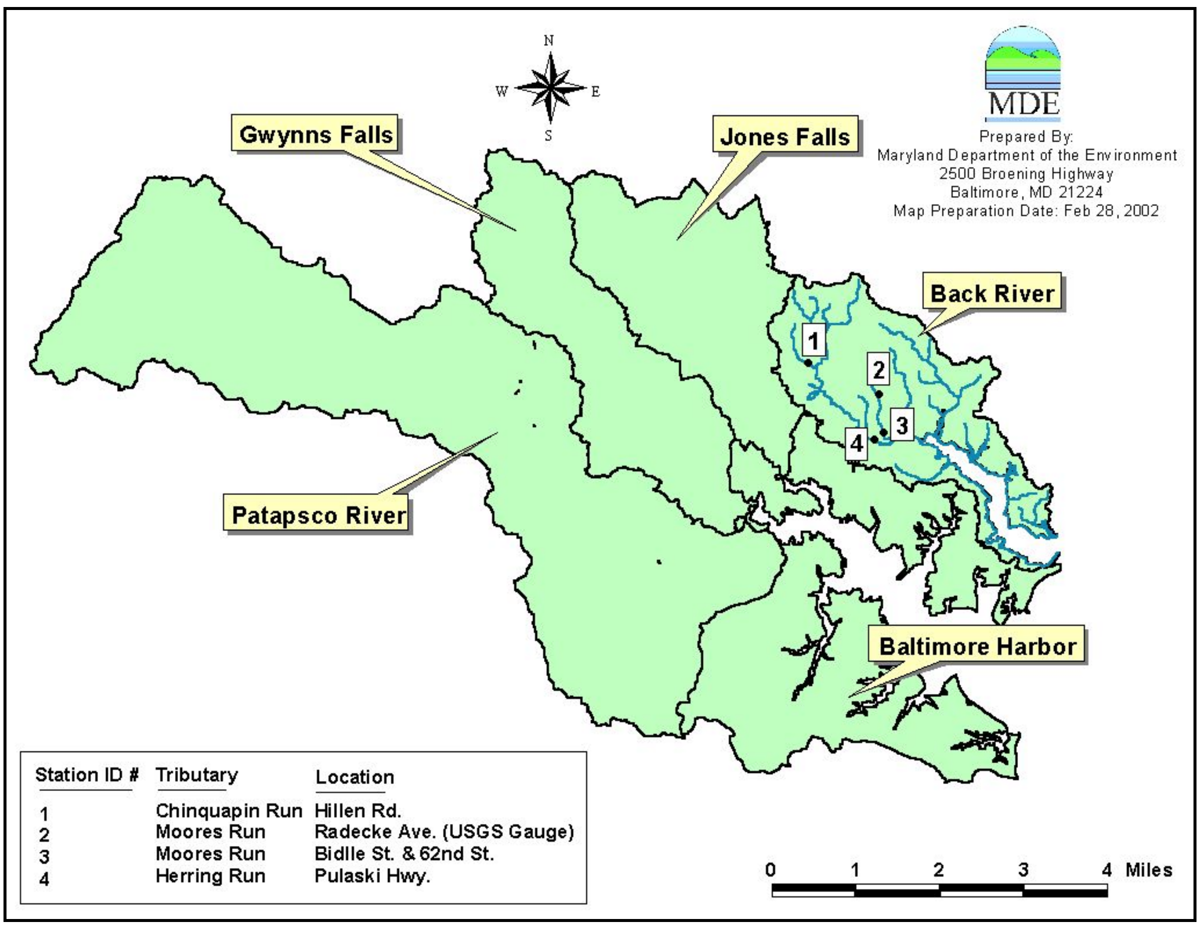

Figure 3.8.3-1: Back River Watershed Baltimore City Sampling Sites

3.8.4 Event Mean Concentration & Unit Load Data

Land use specific Event Mean Concentration (EMC) and unit load data were used as the primary water quality calibration data for the Watershed model. Literature sources containing observed EMC & unit load data for the region included the following: NURP data, NPDES reports (Baltimore County, Baltimore City, Howard, Frederick and Harford County) and Baltimore County Watershed studies. Further refinements of the calibration were performed by comparing model concentration time series and observed grab sampling data. The literature sources and available EMC and unit load data are displayed in Tables 3.8.4-1 and 3.8.4-2, respectively. Land use abbreviations found in the tables represent the following: CI – commercial/industrial, HDR/MDR/LDR – high, medium and low density residential, OPEN – open urban land, PL – pastureland, FL – forestland and CL – cropland. Observed unit load and EMC values and the accompanying literature sources are found in tables 3.8.4-3 to 3.8.4-6 for unit loads and 3.8.4-7 to 3.8.4-11 for EMCs in Appendix G

Table 3.8.4-1: EMC Data Source Summary

Literature Data Source	CI	HDR	MDR	LDR	Water	Open	CL	PL	FL	Barren
Baltimore City NPDES Report (1998)		x	x	x						
Baltimore City NPDES Report (1999)		x	x	x						
Baltimore City NPDES Report (2000)		x	x	x						
Harford County NPDES Report (1999)		x	x	x						
Harford County NPDES Report (2000)		x	x	x						
Frederick County NPDES Report (1999-2000)							x			
Howard County NPDES Report (1999)		x	x	x						
NPDES Monitoring (1992-1995)	x	x	x	x						
NPDES Monitoring (1995-2000)	x	x	x	x						
NURP Residential		x	x	x						
Urbonas and Stahre (1993)							x			
Howard County (1998) - Font Hill Tributary		x	x	x						
Baltimore County Storm Water Monitoring Data (CDM, 1996)	x	x	x	x						
Baltimore County NPDES Monitoring (1990-1995)	x	x	x	x			x		x	
Baltimore County NPDES Report (1998)	x	x	x	x						
Baltimore County NPDES Report (1999)	x	x	x	x						
Baltimore County NPDES Report (2000)	x	x	x	x						

Table 3.8.4-2: Unit Load Data Source Summary

Literature Data Source	CI	HDR	MDR	LDR	Water	Open	CL	PL	FL	Barren
Baltimore City NPDES Report (1997)			X							
Baltimore City NPDES Report (1998)			X							
Baltimore City NPDES Report (1999)			X							
Harford County NPDES Report (1999)		X								
Harford County NPDES Report (2000)		X								
Baltimore County NPDES Report (2000)	X	X	X	X		X	X	X	X	X
Jones Falls Water Quality Management Plan (1997)	X	X	X	X	X	X	X	X	X	X
Loch Raven Water Qulity Management Plan (1997)	X	X	X	X			X	X		
Loch Raven Water Qulity Management Plan (1997) - model	X	X	X	X		X	X	X	X	X
Corsi et al., 1997								X	X	
Horner et al., 1994								X	X	
Smith et al., 1991							X	X	X	
CBP Patapsco/Back River (1984-1994)							X	X	X	
CBP Patapsco/Back River (1984-1997)							X	X	X	
CBP Patapsco/Back River (1993-1997)							X	X	X	
Maryland NPDES Monitoring Report (1997)	X	X	X	X						

3.9 Model Hydrology Parameters

The model hydrology parameters required to characterize a watershed model segmentation within the SWMM RUNOFF Block are segment slope, width, segment area, DCIA, pervious & impervious Manning roughness, minimum & maximum infiltration rates, and pervious & impervious depression storage. DCIA and Manning roughness values are assigned based on a weighted average of the ten land use categories; infiltration rates are assigned based on a weighted average of the four soil groups and the remaining parameters (slope, width, area) are determined using topographical data. Land use and soil specific parameters are found in Table 3.9-1 & 3.9-2. Throughout the model domain, the same land use and soil specific hydrologic parameters are applied to each sub-watershed for model consistency.

Table 3.9-1: Land Use Specific Hydrology Parameters

Land Use	CI	HDR	MDR	LDR	Water	Open	CL	PL	FL	Barren
Directly Connected Impervious Area (DCIA)	70%	47%	31%	25%	100%	1%	1%	1%	1%	1%
Mannings Rougness (Impervious)	0.012	0.012	0.012	0.012	0.1	0.015	0.015	0.015	0.015	0.015
Mannings Rougness (Pervious)	0.15	0.15	0.15	0.15	0.4	0.15	0.15	0.15	0.3	0.03

Table 3.9-2: Soil Type Specific Hydrology Parameters

Soils	A	B	C	D
Minimum Infiltration Rate (in/hr)	0.5	0.25	0.05	0
Maximum Infiltration Rate (in/hr)	9	6	3	1
Infiltration Decay Coefficient	0.00115	0.00115	0.00115	0.00115

3.9.1 Width

In order to calculate width for a model segment, the average length of overland flow must be determined. An average value for overland flow length is measuring by taking several overland flow lengths within a segment using USGS topographical quad maps. Width is calculated using the following equation:

W = A / L.O.F.

W - width of segment (m)
A – Area of segment (m^2)
L.O.F. – Length of overland flow (m)

Width is an empirical parameter used to control the rate at which runoff flows out of a model segment. The widths of sub-watershed model segments are given in Tables 3.9.1-1 to 3.9.1-5 in Appendix H.

3.9.2 Slope

Slope data was obtained from a DEM (30 m grid) coverage created by the University of Maryland using GIS-HYDRO. The DEM coverage was analyzed using Spatial Analyst to compute average slopes for each model segment. Slopes were also estimated manually and compared to GIS values. A further comparison was made to the existing SWMM models developed by Baltimore County. Results showed that GIS computed slopes were lower than manually computed slopes and higher than existing SWMM models. The slopes were reduced, consistently through all model segments, based on existing SWMM model slopes. The slopes of sub-watershed model segments are given in Tables 3.9.2-1 to 3.9.2-5 in Appendix H.

3.9.3 Directly Connected Impervious Area (DCIA)

Directly Connected Impervious Area includes impervious areas that are hydraulically connected to drainage conveyance systems. Impervious areas, which are not connected, are not included in the DCIA value. The values range from 70 % for Commercial/Industrial land use to 1 % for undeveloped land uses (Cropland, Pastureland, Forestland Open Urban and Barren).

The DCIA of sub-watershed model segments is given in Tables 3.9.3-1 to 3.9.3-5 in Appendix H. DCIA land use values for existing studies and the MDE SWMM model are displayed in Table 3.9.3-6. The existing studies are as follows: Soil Conservation Service's TR-55 report and Baltimore County's watershed water quality management plans for Back River, Jones Falls, Lower Gunpowder, Baltimore Harbor and the Patapsco River.

Table 3.9.3-6: Existing Studies DCIA Land Use Values

Land Use	Jones Falls	Back River	Lower Gunpowder	Patapsco	Baltimore Harbor	SCS TR-55	MDE SWMM
Commercial	90%	80%	15%	90%	90%	85%	-
Industrial	-	70%	15%	90%	70%	72%	-
Commercial/Industrial	-	-	-	-	-	-	70%
High Density Residential	60%	45%	12%	60%	50%	65%	47%
Medium Density Residential	25%	20%	8%	25%	30%	25% - 45%	31%
Low Density Residential	15%	10%	5%	15%	15%	12% - 25%	25%
Open Urban Land	4%	3%	1%	4%	3%	-	1%
Cropland	3%	-	0%	3%	1%	-	1%
Pastureland	5%	-	0%	5%	1%	-	1%
Agricultural	-	1%	4%	-	-	-	-
Forestland	2%	1%	0%	2%	1%	-	1%
Barren	2%	0%	0%	2%	3%	-	1%
Water/Wetlands	100%	100%	80/50%	100%	100%	-	100%

3.9.4 Manning Roughness

Manning roughness is a coefficient that defines the roughness of ground cover for different land uses. A value for pervious and impervious ground cover within a land use is chosen. Impervious values range from 0.015 for undeveloped land uses to 0.012 for developed land uses (Commercial Industrial, Residential and Open Urban). Pervious values range from 0.3 for forestland to 0.03 for barren land use. Manning roughness land use values for existing studies and the MDE SWMM model are displayed in Table 3.9.4-1.

Table 3.9.4-1: Existing Studies Manning Roughness Land Use Values

	Jones Falls		Back River		Lower Gunpowder		Baltimore Harbor		MDE SWMM	
Land Use	Impervious n	Pervious n	Impervious n	Pervious n	Impervious n	Pervious n	Impervious n	Pervious n	Impervious n	Pervious n
Commercial	0.012	0.15	0.015	0.25	0.014	0.2	0.015	0.25	-	-
Industrial	0.012	-	0.015	-	0.014	0.2	0.015	0.25	-	-
Commercial/Industrial	-	-	-	-	-	-	-	-	0.012	0.15
High Density Residential	0.012	0.15	0.015	0.25	0.014	0.2	0.015	0.25	0.012	0.15
Medium Density Residential	0.012	0.15	0.015	0.25	0.014	0.2	0.015	0.25	0.012	0.15
Low Density Residential	0.012	0.15	0.015	0.25	0.014	0.2	0.015	0.25	0.012	0.15
Open Urban Land	0.012	0.15	0.015	0.3	0.02	0.2	0.015	0.25	0.015	0.15
Cropland	0.015	0.15	-	-	0.17	0.17	0.015	0.2	0.015	0.15
Pastureland	0.015	0.15	-	-	0.17	0.35	0.015	0.2	0.015	0.15
Agricultural	-	-	0.015	0.4	0.17	0.17	-	-	-	-
Forestland	0.015	0.3	0.015	0.3	.1 - .4	0.4	0.015	0.3	0.015	0.3
Barren	0.024	0.04	0.024	0.3	0.03	0.03	0.015	0.25	0.015	0.03
Water/Wetlands	0.0001	0.0001	0.1	0.4	0.06	0.06	0.001	0.001	0.1	0.4

3.9.5 Depression Storage

Depression storage is the volume of water that must be filled before surface flow can occur on pervious and impervious areas. Storage depletes rapidly on pervious areas due to infiltration & evaporation during dry weather. For impervious areas, evaporation is the only means of depletion during dry weather. Values for depression storage are assigned based on land use groups. A pervious value of 0.05 and impervious value of 0.02 is chosen for all land uses. These values were selected based on literature review and calibration.

3.9.6 Infiltration

Infiltration rates are determined based on an area weighted average of the soil type distribution for each model segment. The model requires a maximum and minimum infiltration rate. The Horton method of infiltration is chosen for the model. The Horton equation is as follows (USEPA, 2000):

$$f = f_c + (f_o - f_c)\, e^{-kt}$$

f = infiltration capacity at time = t, in/hr
f_c = minimum infiltration capacity, in/hr
f_o = maximum or initial infiltration rate, in/hr
k = infiltration decay rate, 1/day
t = time, days

The values for maximum and minimum infiltration rate range from 9 in/hr to 1 in/hr and 0.5 in/hr to 0 in/hr, respectively for soil type groups A to D. An infiltration decay rate of 0.00115 has been chosen based on suggestion from the SWMM manual and values used in Baltimore County watershed studies. For a continuous simulation, SWMM requires a regeneration parameter that defines the rate at which infiltration capacity recovers once surface flow has ended. The regeneration parameter is multiplied by the infiltration decay rate, k, to give a Horton type exponential rate constant, k_d. Based on calibration, a regeneration parameter of 0.00069 was chosen for this model. The regeneration equation is as follows (USEPA, 2000):

$$f = f_o - (f_o - f_c)\, e^{-k_d (t-t_w)}$$

k_d = regeneration decay rate 1/day
t_w = hypothetical projected time at which $f = f_c$, days

Maximum and minimum infiltration rates by soil type for existing studies and the MDE SWMM model are displayed in Table 3.9.6-1.

Table 3.9.6-1: Existing Studies Soil Type Infiltration Rates

	Jones Falls		Back River		Lower Gunpowder		Patapsco		Baltimore Harbor		MDE SWMM	
Soil Group	f_{max} (in/hr)	f_{min} (in/hr)	f_{max} (in/hr)	f_{min} (in/hr)	f_{max} (in/hr)	f_{min} (in/hr)	f_{max} (in/hr)	f_{min} (in/hr)	f_{max} (in/hr)	f_{min} (in/hr)	f_{max} (in/hr)	f_{min} (in/hr)
A	9	0.45	5	0.5	5	0.45	2	0.065	5	0.3	9	0.5
B	6	0.2	3	0.25	4	0.3	1.5	0.05	3	0.15	6	0.25
C	4	0.1	1.5	0.05	3	0.15	1	0.025	1.5	..5	3	0.05
D	2	0.05	0.5	0	1.5	0.05	0.5	0.02	1	0	1	0

3.10 Model Water Quality Parameters

The Water quality constituents being modeled are TSS, Cr, Cu, Zn and Pb. The delivered metals load is based on empirical build up and wash off equations incorporated in the RUNOFF Block of the SWMM model. Concentrations are back-calculated from the edge of stream flow. Build up and wash off equations are used to calculate the four metals (Cr, Cu, Zn and Pb) edge of stream loads for all land use groups. For TSS, developed land is modeled using build up and wash off equations and the undeveloped lands (Cropland, Pastureland, Forestland, Open Urban and Barren) are modeled using the USLE to predict the surface erosion and watershed delivery.

3.10.1 Pollutant Build-up

As discussed previously, build up and wash off is used to simulate metals from all land uses and TSS from developed land uses. A linear build-up rate is assigned for each land uses. The equation applied within the model is as follows (USEPA, 2000):

$$PSHED = QFACT(3)*t^{QFACT(2)}$$

$$PSHED<=QFACT(1)$$

PSHED – surface build-up at time t, lb/acre

QFACT(1) – maximum surface build-up, lb/acre

QFACT(2) – surface build-up exponent, dimensionless

QFACT(3) – surface build-up coefficient, lb/acre/day

t – time, days

QFACT(2) is chosen as 1 in order to linearize the equation. QFACT(3) is than defined as the surface build-up rate. A linear build-up rate is the most simplistic approach and a good starting point for model development. Linear build up rate was also used in the Jones Falls Watershed Study (Dames & Moore, 1997). A high upper build up limit was input thus allowing the model to simulate a constant and continuous build up over dry periods.

3.10.2 Pollutant Wash-off

The washoff formulation equation applied within the model is as follows (USEPA, 2000):

$$POFF = PSHED_o*(1.0 - e^{-Kt})$$

$$K=RCOEF*r^{Washpro}$$

POFF = cumulative pollutant load washed off at time t, lbs/ac

K = first order decay rate

RCOEF = wash-off coefficient, in^{-1}

WASPO = power exponent for runoff rate

PSHED = pollutant mass available for wash-off, lbs/ac

r = runoff rate during time interval, in/hr

t = time interval, hr

For this model a WASPO of 1.5 and a RCOEF of 9 were chosen based on ranges given in the literature data. The SWMM manual suggests that WASPO and RCOEF be within the range of 1.5 – 2.5 and 1 – 10, respectively. In the Baltimore county watershed studies

(Jones Falls, Back River, Patapsco and Lower Gunpowder) WASPO values were either 1 or 1.5 and RCOEF values ranged from 4.6 –10. The values chosen for the model fall within the range of values suggested by the SWMM manual and those used in previous sub-watershed studies in the Patapsco/Back River.

3.10.3 Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation is an estimate of soil erosion from rainstorms for a specific land use. Soil loss is calculated as a load over the time step during storm events in which surface runoff occurs. The equation used within the SWMM model is as follows (USEPA, 2000):

$$L = R*K*LS*C*P$$

L – soil loss, lb/acre/Δt
R – rainfall factor
K – soil erodibility factor,
LS – slope length gradient ratio
C – cropping management factor
P – erosion control practice factor
Δt – time period

The parameter for K is based on soil type, C is based on land use cover and P is based on cropping practices. The area of each segment subject to erosion is defined as the total pervious area within the model segment.

The slope length gradient ratio, LS, is calculated using the following equation:

$$LS = ERLEN^{0.5} * (0.0076 + 0.53*WSLOPE + {}^{7}/_{6}*WSLOPE^{2})$$

ERLEN – the length in feet from the point of origin of overland flow to the point where the slope decreases to the extent that deposition begins or to the point at which runoff enters a defined channel
WSLOPE – the average slope over the given runoff length

A constant ERLEN is chosen as 300 feet, which correlates with the average overland flow length defined by the SCS (SCS, 1986). The WSLOPE is defined in the model as the average slope of the model segment

The soil factor, K, is a measure of the potential erodibility of a soil. The values range from 0.3 - 0.4 for the different hydrologic soil types.

The cropping management factor, C, is dependent upon the type of ground cover, the management practice and the condition of soil over the area of concern. The values range from 0.005 to 0.05 for forestland to cropland. Erosion occurs most readily from cropland due to loose soil from tilling practices.

The control practice factor, P, accounts for erosion control practices.

The rainfall factor, R, is the product of the maximum thirty-minute rainfall intensity for the time of simulation and the sum of rainfall energy over the time step. The equation for energy is as follows:

$$E = \sum[9.16 + 3.31*\log_{10}(RNINHRj)]*RNINHRj*DELT$$

E = total rainfall energy for time step, ft-ton/acre
RNINHRj – rainfall intensity, in/hr
DELT – time step, hr

$$R = E*RAINIT$$

RAINIT – maximum average 30 minute rainfall intensity for the time of simulation, in/hr
R – rainfall factor, ft-ton-in/acre-hr

In order to calculate the rainfall intensity factor a summary of rainfall intensities from the BWI rain gauge was made. The maximum one-hour rainfall intensity was extracted for each storm event of the model simulation period and a storm event volume weighted average of all the peak intensities was calculated.

Land use specific cropping management factors were based on existing USLE values and then refined to better match regional values suggested by the CBP. Cropping management factor and control practice values are listed in Table 3.10.3-1. The soil factor (K), based on soil type, are listed in Table 3.10.3-2. For comparison, Table 3.10.3-1 lists C & P values suggested in the SWMM model for the Little Kanawha Watershed TMDL in West Virginia. (USEPA-Region 3, 2000) It is important to note that loads are still driven by the rainfall intensity factor calculated for the region.

Table 3.10.3-1: USLE C & P Parameters

	MDE SWMM		Little Kanawha	
Land Use	**C**	**P**	**C**	**P**
Open	0.0045	1	0.003	1
Cropland	0.0465	0.3	0.08	0.5
Pastureland	0.01	1	0.01	1
Forestland	0.0028	1	0.005	1
Barren	0.0042	1	0.5	-

Table 3.10.3-2: USLE K Parameters

Soil Type	MDE SWMM
A	0.3
B	0.4
C	0.4
D	0.3

3.10.4 Base Flow Concentrations

Constant base flow concentrations are assigned in each sub-watershed for the model by averaging values from observed dry weather data sources. These sources include the MDE Upper Western Shore monitoring program, Baltimore County DEPRM base flow data, Baltimore City Wastewater Facilities Master Plan and Annual NPDES reports for Baltimore County and City. Resulting base flow concentration values are displayed in Table 3.10.4-1. Sources of base flow concentration per constituent are listed in Table 3.10.4-2.

Table 3.10.4-1: SWMM Model Base Flow Concentrations

Constituent	Gwynns Falls	Jones Falls	Patapsco River	Baltimore Harbor	Back River
TSS (mg/L)	4.17	5.15	6.19	4.66	3.06
Cr (mg/L)	0.00075	0.00062	0.00081	0.00069	0.00048
Cu (mg/L)	0.0093	0.0058	0.0051	0.00755	0.0062
Zn (mg/L)	0.0184	0.0229	0.0154	0.02065	0.0286
Pb (mg/L)	0.0017	0.0017	0.0017	0.0017	0.0017

Table 3.10.4-2: SWMM Model Base Flow Concentration Data Sources

Base Flow Data Source	TSS	Cr	Cu	Zn	Pb
Baltimore County NPDES Report (2000)					X
Baltimore City NPDES Report (2001)					X
Baltimore City Wastewater Facilities Master Plan (1997)	X		X	X	X
Baltimore County DEPRM Watershed Monitoring Project (1997-2000)	X				
MDE Upper Western Shore Monitoring Project (2001)		X			

The TRANSPORT block does not internally calculate base flow concentrations. The model allows the input of base flow concentrations. It is assumed the base flow concentrations are constant for the model simulation period (1/1/92 – 9/30/01). The sensitivity of base flow loads is minimal for TSS, since TSS is mostly rainfall event driven. In addition the four metals (Cr, Cu, Zn & Pb) have a high affinity for TSS and thus dry weather loads tend to be much less than wet weather loads. The only exception is copper, which for this study has a base flow contribution of about 24%.

4 Hydrology Calibration

4.1 Hydrology Calibration Procedure

Four of the five sub watersheds (Jones Falls, Gwynns Falls Patapsco River and Back River) have active USGS flow gauge stations that are used for the SWMM model hydrology calibration. There are a total of seven USGS stations located within the Patapsco/Back River watershed. Two stations are located in the Back River Watershed, two stations in Jones Falls, two stations in Gwynns Falls and one station in Patapsco River. The most downstream gauge in Jones Falls & Gwynns Falls is used to validate the hydrology calibration due to the limited amount of observed data.

The watersheds were delineated to include the drainage basin to all flow gauge locations so a comparison of the modeled and observed flow data could be made. A series of observed and model results comparisons are used to qualify and quantify the model calibration. They are listed as follows: daily average flow frequency, cumulative volume comparison and daily, monthly, seasonal and annual flow time series comparisons.

A parallel watershed study by MDE, using HSPF to generate flow and nutrient loads within the Patapsco/Back River is currently in progress. The simulation period for this model is 1/1/92 – 9/30/98. The model time period was selected based on available nutrient and flow data. A comparison was made between the SWMM model and HSPF model hydrology output at three stations. One in Jones Falls, one in Gwynns Falls and one in the Patapsco River watershed. Due to the length of the HSPF simulation period, a comparison could only be made to these three gauges.

For the Patapsco River watershed, the SWMM hydrology was compared to the Chesapeake Bay Program Watershed Model for the time period of 3/31/94 to 9/30/95. This time period reflects the dates of which the USGS gauge was active. Due to the coarse segmentation of the CBP HSPF model, this was the only site within the Patapsco/Back River watershed that was directly comparable.

4.2 Hydrology Calibration Results

The series of calibration charts defined in the preceding section for the Jones Falls watershed calibration are displayed in figures 4.2-1 to 4.2-6. A comparison of the MDE SWMM and MDE HSPF model is made. The series of calibration figures for the six remaining USGS gauges are found in Appendix I

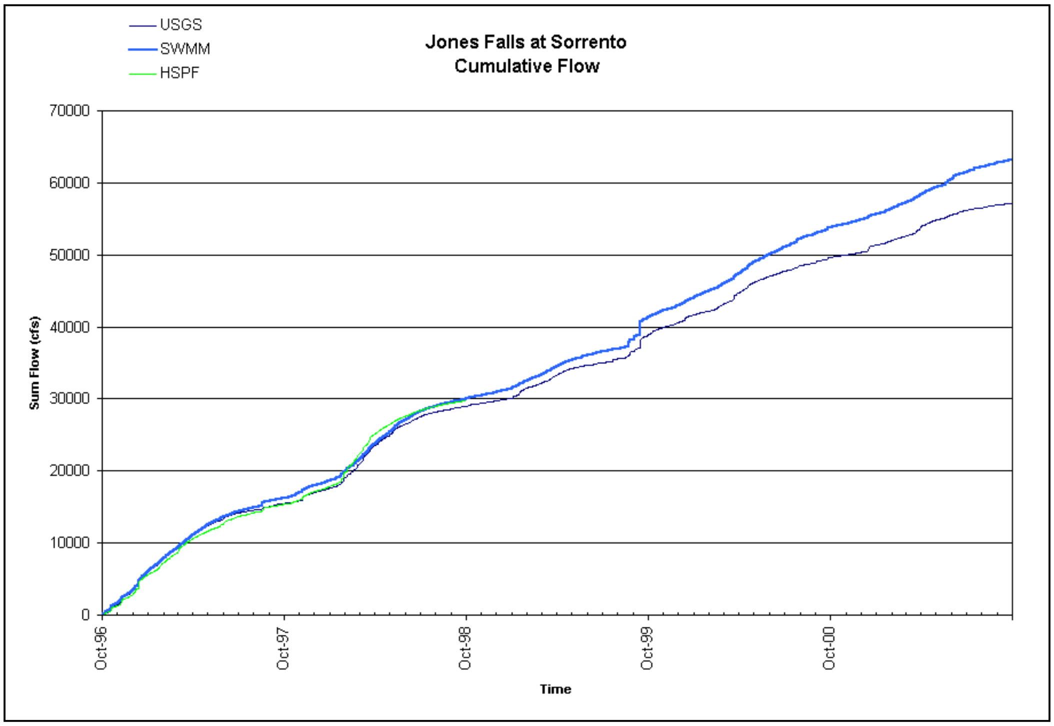

Figure 4.2.1-1: Jones Falls Cumulative Flow (Sorrento USGS Flow Gauge)

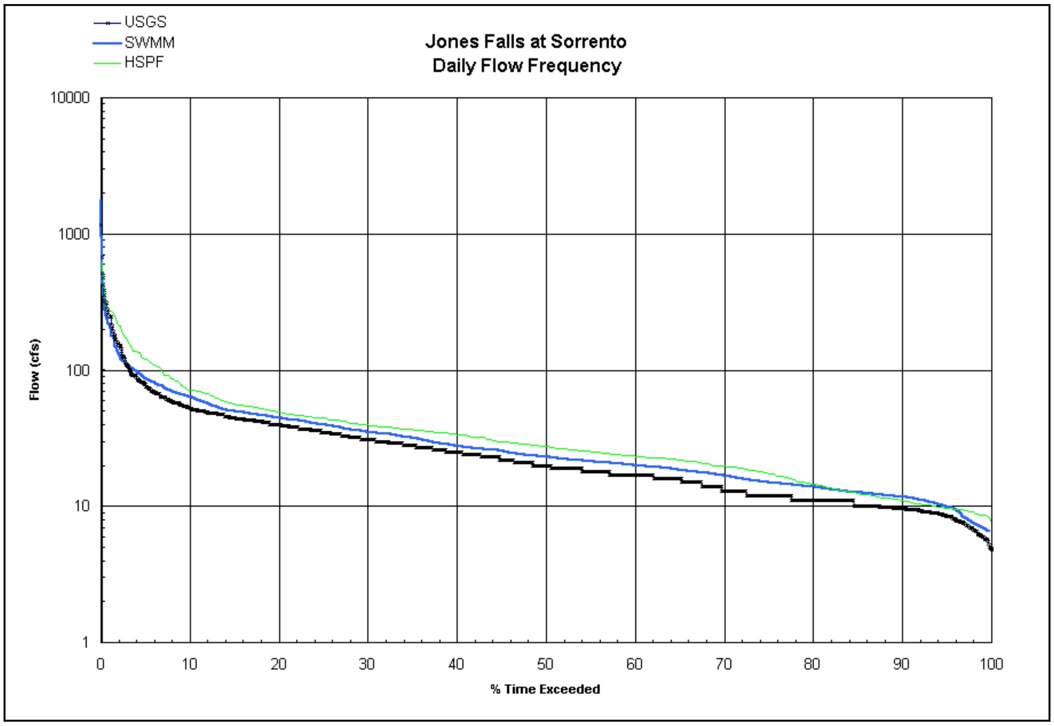

Figure 4.2.1-2: Jones Falls Daily Flow Frequency (Sorrento USGS Flow Gauge)

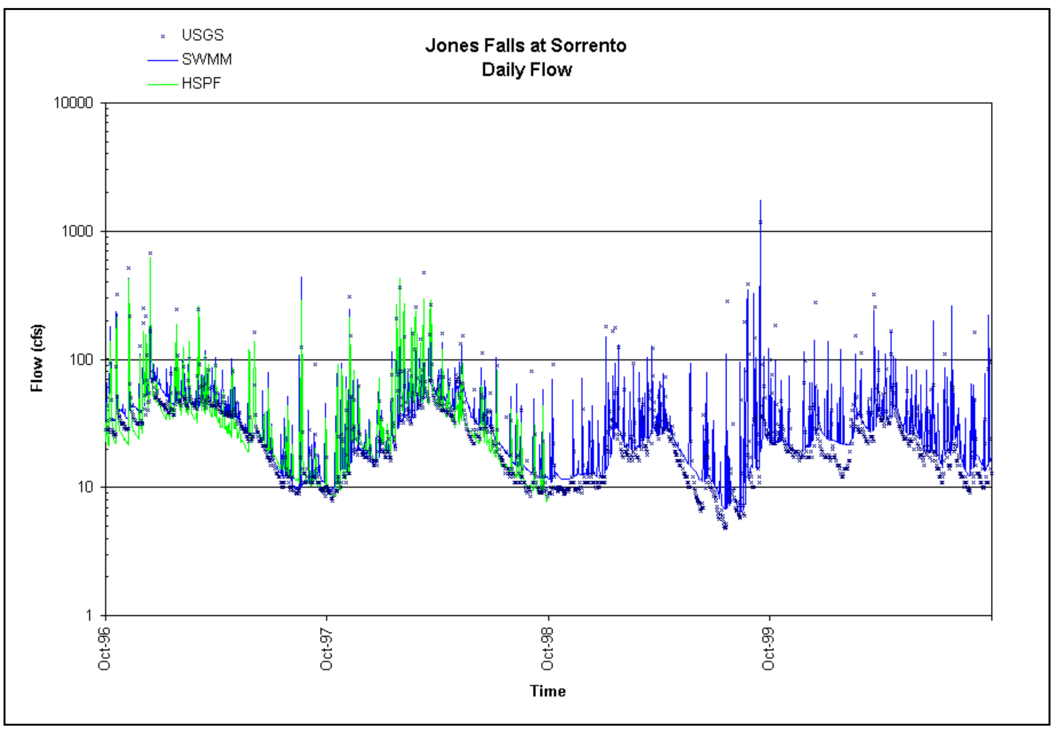

Figure 4.2.1-3: Jones Falls Daily Flow Time Series (Sorrento USGS Flow Gauge)

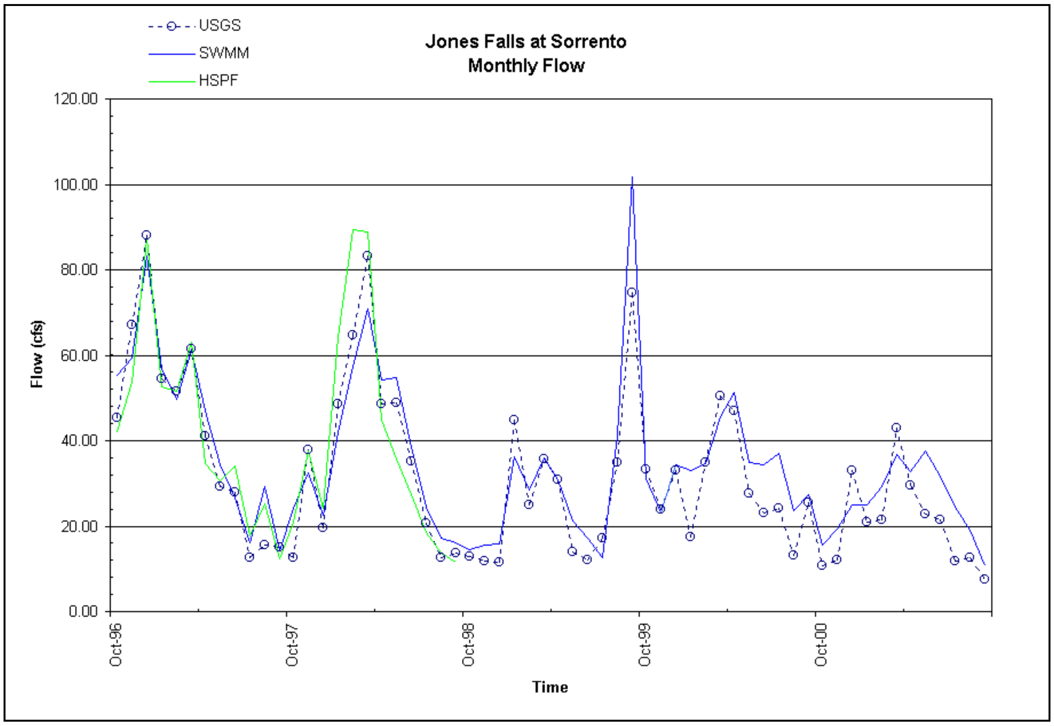

Figure 4.2.1-4: Jones Falls Monthly Flow Time Series (Sorrento USGS Flow Gauge)

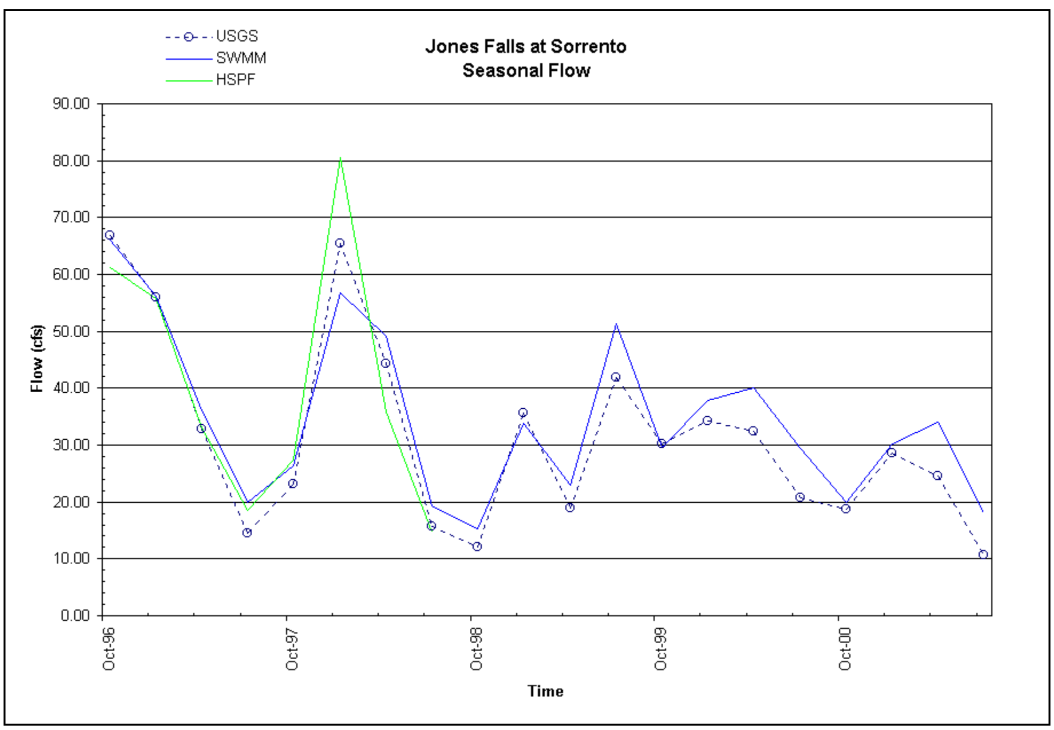

Figure 4.2.1-5: Jones Falls Seasonal Flow Time Series (Sorrento USGS Flow Gauge)

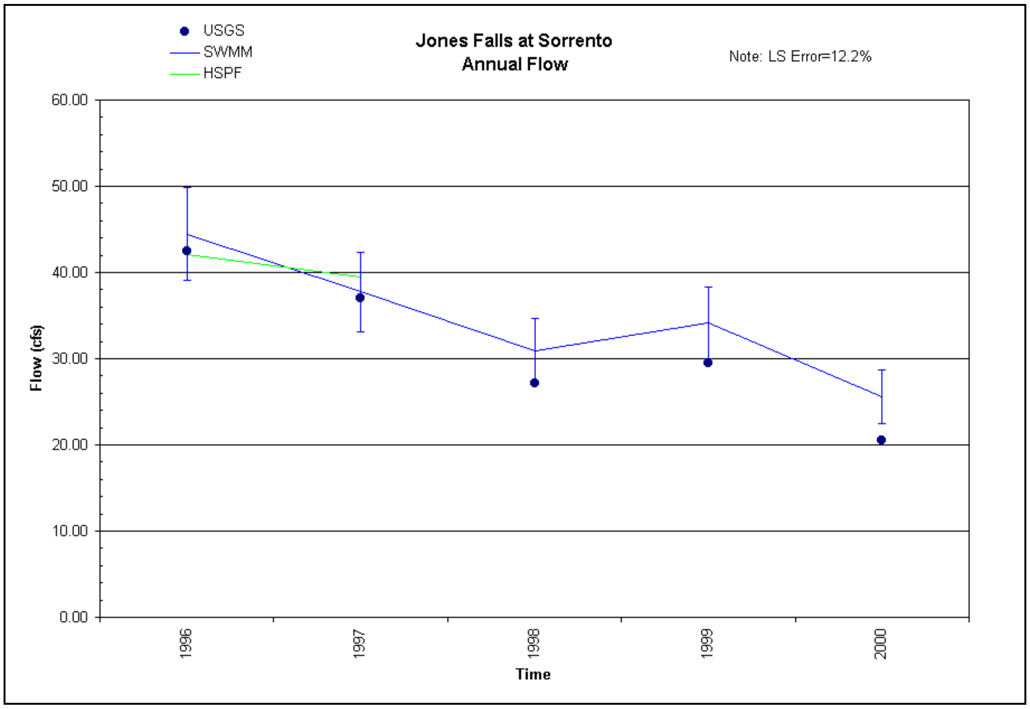

Figure 4.2.1-6: Jones Falls Annual Flow Time Series (Sorrento USGS Flow Gauge)

*Error bars represent least squares average error

A least squares (relative error) and R^2 (correlation) statistical analysis was performed on monthly, seasonal and annual flows for each USGS gauge location. The statistical results on a monthly, seasonal and annual basis for the SWMM & HSPF models are shown below in Tables 4.2-1, 4.3-2, and 4.2-3. The SWMM model statistical values with an asterisk were calculated to 9/30/1998 in order that they may be compared with the HSPF model statistical values. The statistical errors for the flow station in Back River at Moores Run are unusually high when compared with the other gauges. This is due to a significant loss of base flow to infrastructure through infiltration. An existing drainage system is directly under the Moores run streambed.

Table 4.2-1: SWMM Model Hydrology Monthly Statistical Analysis

Model	Flow Station	Drainage Area (acres)	Begin Date	End Date	Monthly LS Error %	Monthly R^2
SWMM	Gwynns Falls at Villa Nova	20814	10/01/1996	09/30/2001	23.8/21.4*	0.729/0.904*
HSPF	Gwynns Falls at Villa Nova	21018	10/01/1996	09/30/1998	22.8	0.807
SWMM	Jones Falls at Sorrento	16946	10/01/1996	09/30/2001	27.1/19.5*	0.866/0.932*
HSPF	Jones Falls at Sorrento	16490	10/01/1996	09/30/1998	18.4	0.85
SWMM	Patapsco River at Hollofield	76539	03/31/1994	09/30/1995	40.7	0.932
HSPF	Patapsco River at Hollofield	77226	03/31/1994	09/30/1995	21.1	0.448
CBP	Patapsco River at Hollofield	77518	03/31/1994	09/30/1995	39.3	0.574
SWMM	Patapsco River at Hollofield	76539	01/01/2000	09/30/2001	15.4	0.781
SWMM	Back River at Herring Run	1296	01/01/1997	09/30/2001	27.5	0.833
SWMM	Back River at Moores Run	2273	07/23/1996	09/30/2001	66.3	0.85
SWMM	Gwynns Falls at Washington Ave.	40329	10/01/1998	09/30/2001	24	0.84
SWMM	Jones Falls at Maryland Ave.	37700	10/27/1999	09/30/2001	22.5	0.737

Table 4.2-2: SWMM Model Hydrology Seasonal Statistical Analysis

Model	Flow Station	Drainage Area (acres)	Begin Date	End Date	Seasonal LS Error %	Seasonal R^2
SWMM	Gwynns Falls at Villa Nova	20814	10/01/1996	09/30/2001	17.3/15.6*	0.822/0.989*
HSPF	Gwynns Falls at Villa Nova	21018	10/01/1996	09/30/1998	15.9	0.901
SWMM	Jones Falls at Sorrento	16946	10/01/1996	09/30/2001	19.3/13.9*	0.937/0.972*
HSPF	Jones Falls at Sorrento	16490	10/01/1996	09/30/1998	10.7	0.931
SWMM	Patapsco River at Hollofield	76539	03/31/1994	09/30/1995	36.9	0.941
HSPF	Patapsco River at Hollofield	77226	03/31/1994	09/30/1995	24	0.713
CBP	Patapsco River at Hollofield	77518	03/31/1994	09/30/1995	-	-
SWMM	Patapsco River at Hollofield	76539	01/01/2000	09/30/2001	10.4	0.837
SWMM	Back River at Herring Run	1296	01/01/1997	09/30/2001	18.5	0.85
SWMM	Back River at Moores Run	2273	07/23/1996	09/30/2001	50.8	0.838
SWMM	Gwynns Falls at Washington Ave.	40329	10/01/1998	09/30/2001	18	0.878
SWMM	Jones Falls at Maryland Ave.	37700	10/27/1999	09/30/2001	16.6	0.933

Table 4.2-3: SWMM Model Hydrology Annual Statistical Analysis

Model	Flow Station	Drainage Area (acres)	Begin Date	End Date	Annual LS Error %	Annual R^2
SWMM	Gwynns Falls at Villa Nova	20814	10/01/1996	09/30/2001	6.9/6.9*	-
HSPF	Gwynns Falls at Villa Nova	21018	10/01/1996	09/30/1998	3.4	-
SWMM	Jones Falls at Sorrento	16946	10/01/1996	09/30/2001	12.2/3.4*	-
HSPF	Jones Falls at Sorrento	16490	10/01/1996	09/30/1998	2.1	-
SWMM	Patapsco River at Hollofield	76539	03/31/1994	09/30/1995	-	-
HSPF	Patapsco River at Hollofield	77226	03/31/1994	09/30/1995	-	-
CBP	Patapsco River at Hollofield	77518	03/31/1994	09/30/1995	-	-
SWMM	Patapsco River at Hollofield	76539	01/01/2000	09/30/2001	-	-
SWMM	Back River at Herring Run	1296	01/01/1997	09/30/2001	11.4	0.894
SWMM	Back River at Moores Run	2273	07/23/1996	09/30/2001	49.5	0.961
SWMM	Gwynns Falls at Washington Ave.	40329	10/01/1998	09/30/2001	13.8	-
SWMM	Jones Falls at Maryland Ave.	37700	10/27/1999	09/30/2001	7.8	-

5 Water Quality Calibration

5.1 Water Quality Calibration Procedure

A comparison of land use specific model EMC and unit loads vs. observed EMC and unit loads was used to calibrate the water quality component of the model. In order to calibrate the water quality component of the model a comparison of land use specific model and observed EMC and Unit Load data was performed. An extensive local literature survey was conducted to find all available observed EMC and unit load data to support the validity of the water quality calibration. The build-up rate is chosen as the only water quality parameter to be adjusted for calibration. All other water quality parameters for buildup and wash off are kept constant based on literature values, this allows for the input of a unique set of parameters within the model. The upper build up limit was set high to allow for continuous build up of pollutants during dry weather periods. TSS calibration for undeveloped lands requires adjusting the USLE cropping management factor until edge of stream loads are calibrated with local observed values. The cropping management factor is kept within the suggested literature ranges.

A comparison of observed data and model concentration time series is made in order to validate the water quality calibration. The concentration time series comparisons show the model captures the general trend of water quality but does not match every storm event. Due to the spatial limits of precipitation estimates and the simplicity of the constituent run-off process within the model, SWMM does not have the capability to capture all events. Furthermore, the purpose of this watershed model is to simulate flows and loads from the tributary systems (Jones Falls, Gwynns Falls and Patapsco River) that flow into the Baltimore Harbor. The model flows and loads will be input to a Baltimore Harbor hydrodynamic and water quality estuarine model as part of a Baltimore Harbor TMDL project. The estuarine models do not require a watershed model calibration with a high degree of detail, in order to be applicable to the TMDL project. A watershed TMDL is not being developed using this model.

5.2 Water Quality Calibration Results

EMC & unit load comparison Figures 5.2-1 to 5.2-5 display the average model EMC & unit load values for the entire Patapsco/Back River Watershed with error bars representing the maximum and minimum values from the five sub-watersheds. The top chart is the EMC comparison and the bottom chart is the annual unit load. EMCs and unit loads have units of mg/L and lb/acre/year, respectively. In the EMC chart, the first bar represents the SWMM model average EMC value for all storm events within the simulation period, the second bar is the average observed values, the third and forth bar are the Maryland NPDES EMC values for 1992-1995 and 1995-2000, respectively. NPDES EMC data only exists for residential and commercial/industrial land uses. The base line represents the average base flow concentration of the five sub-watersheds. In the unit load chart, the first bar represents the SWMM model annual unit load value averaged over the entire simulation period and second bar represents the average observed values. The base line is the average unit load contributed by base flow of the five sub-watersheds. Error bars in both charts denote the range of unit loads and EMC's from the five sub-waterhshed models.

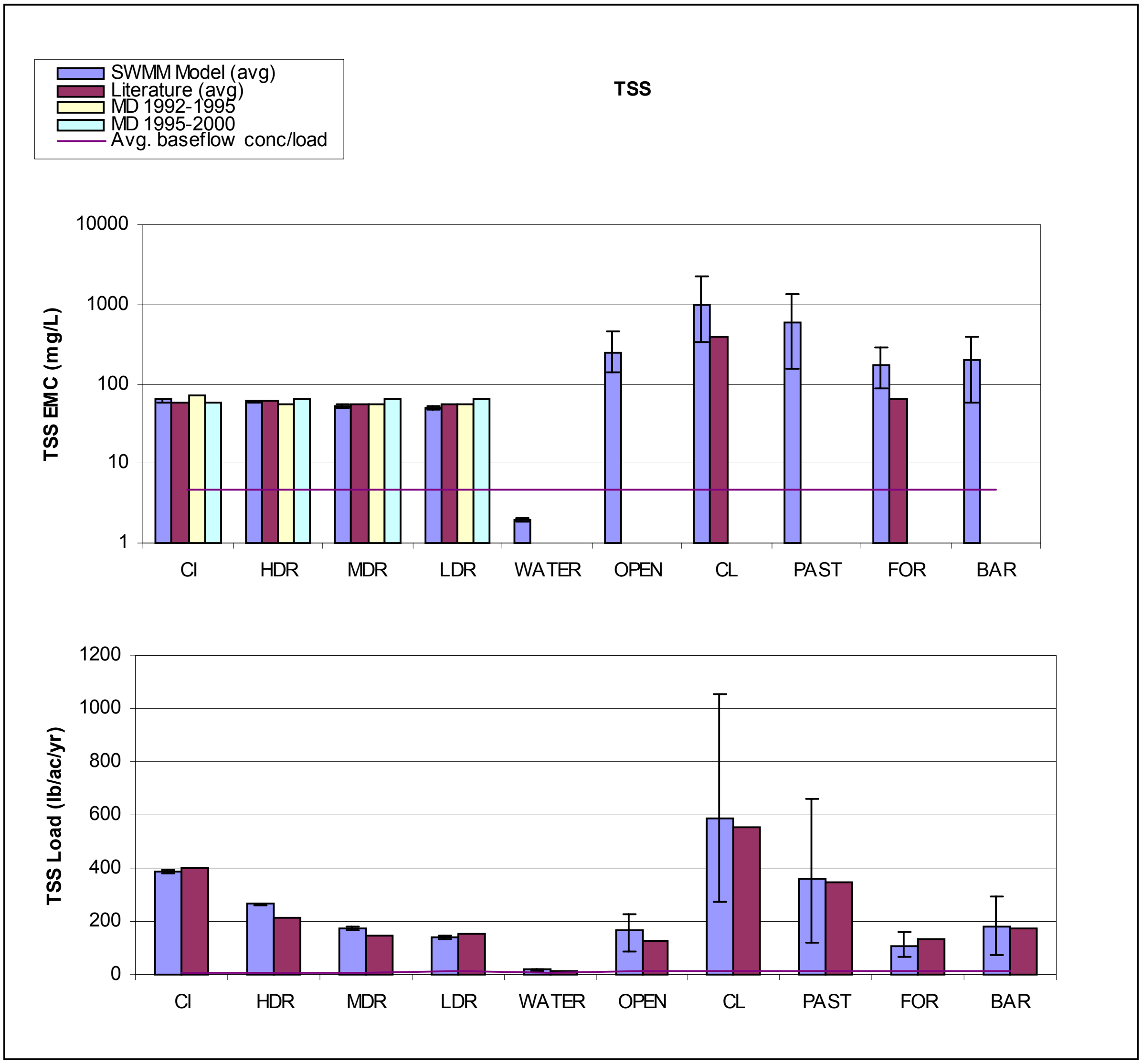

Figure 5.2.1-1: TSS EMC & Unit Load Comparison

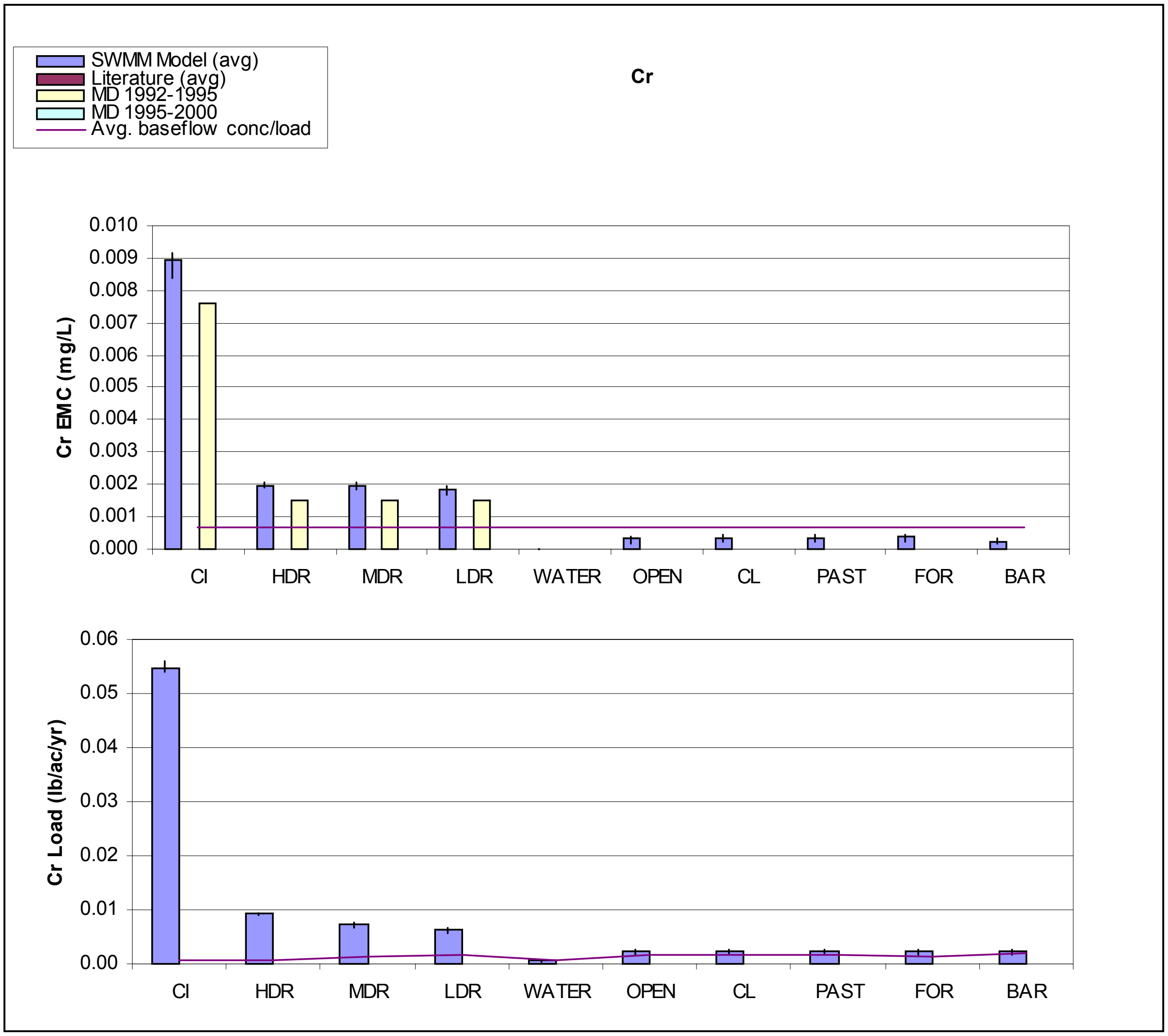

Figure 5.2.1-2: Cr EMC & Unit Load Comparison

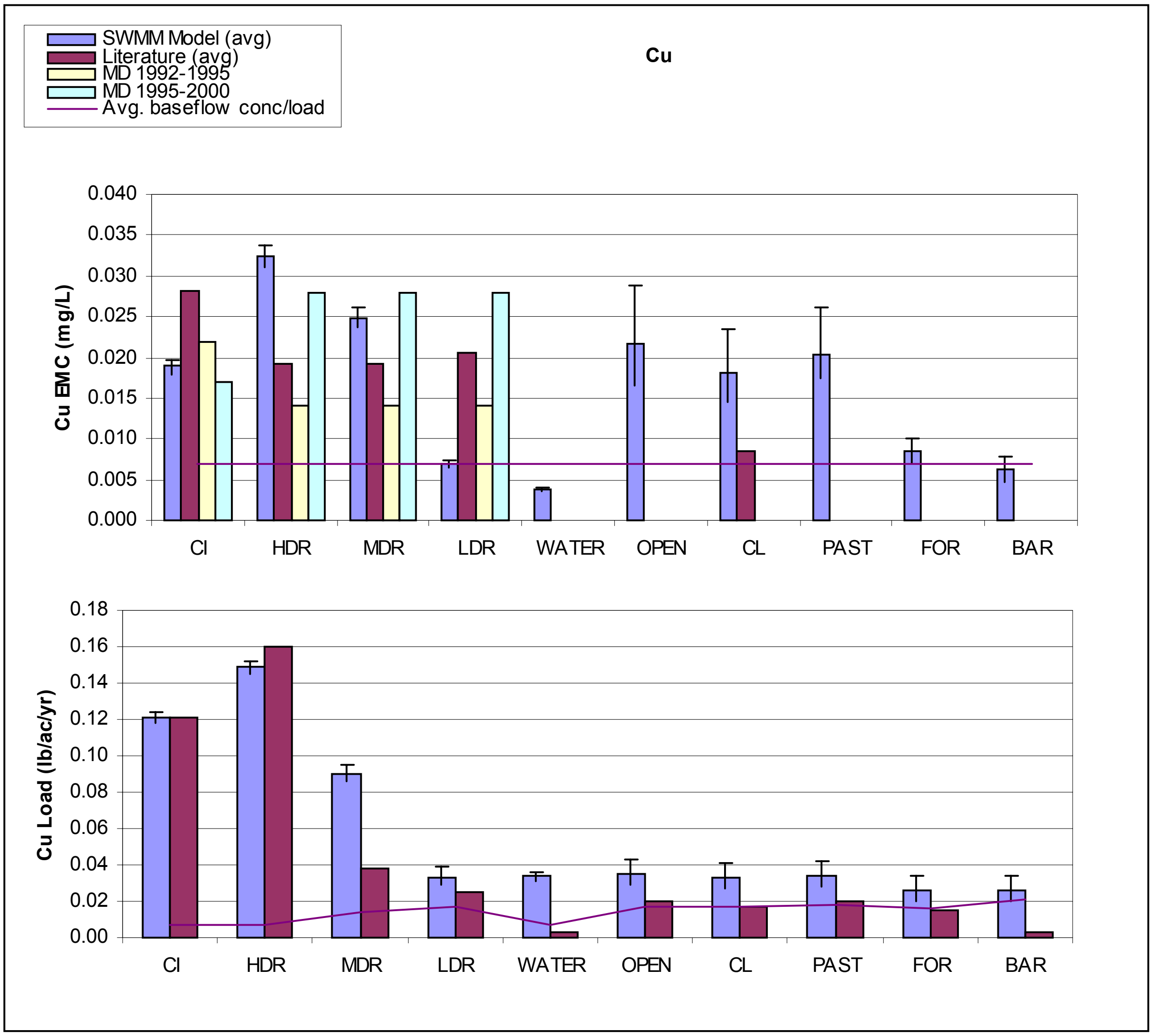

Figure 5.2.1-3: Cu EMC & Unit Load Comparison

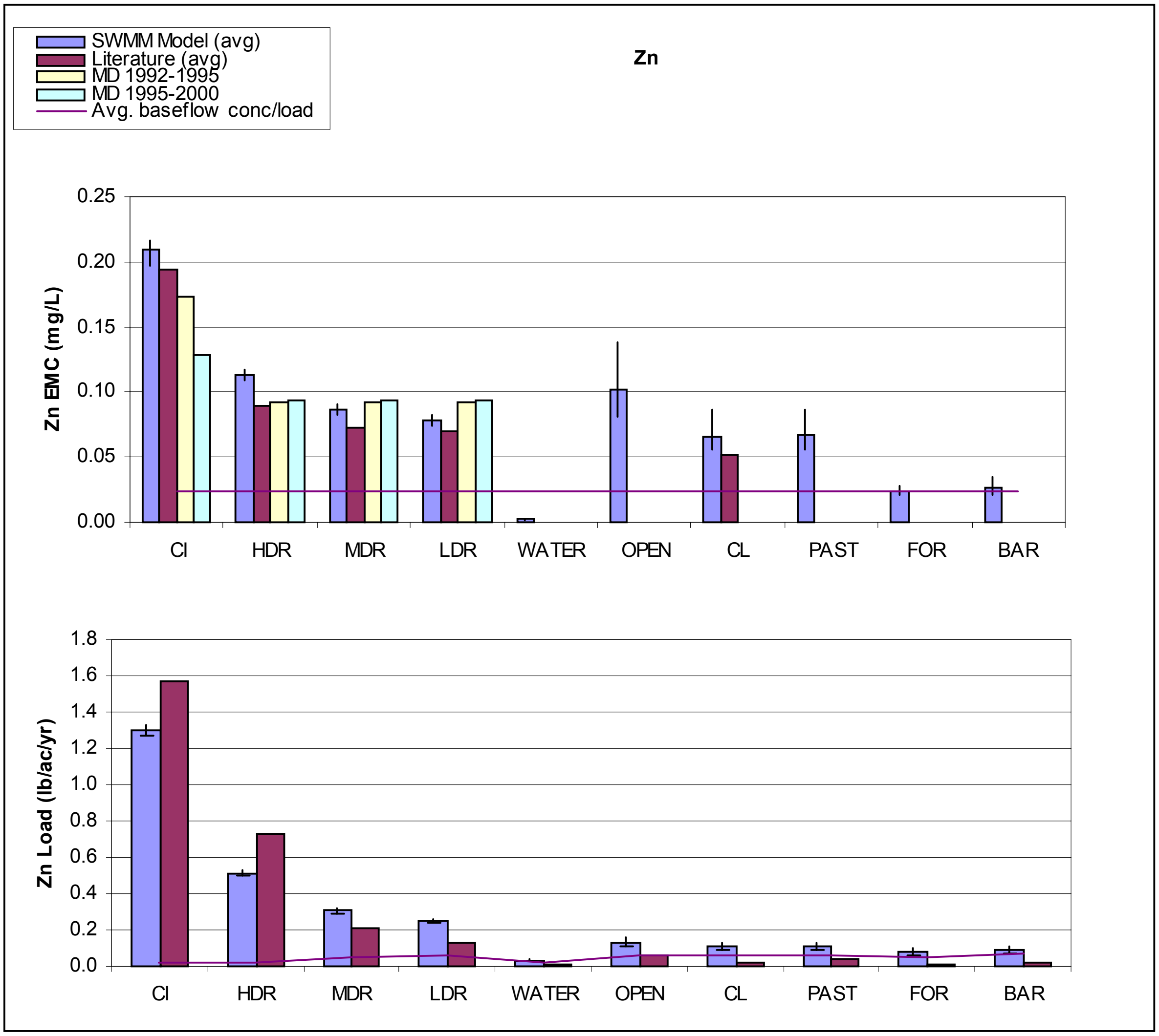

Figure 5.2.1-4: Zn EMC & Unit Load Comparison

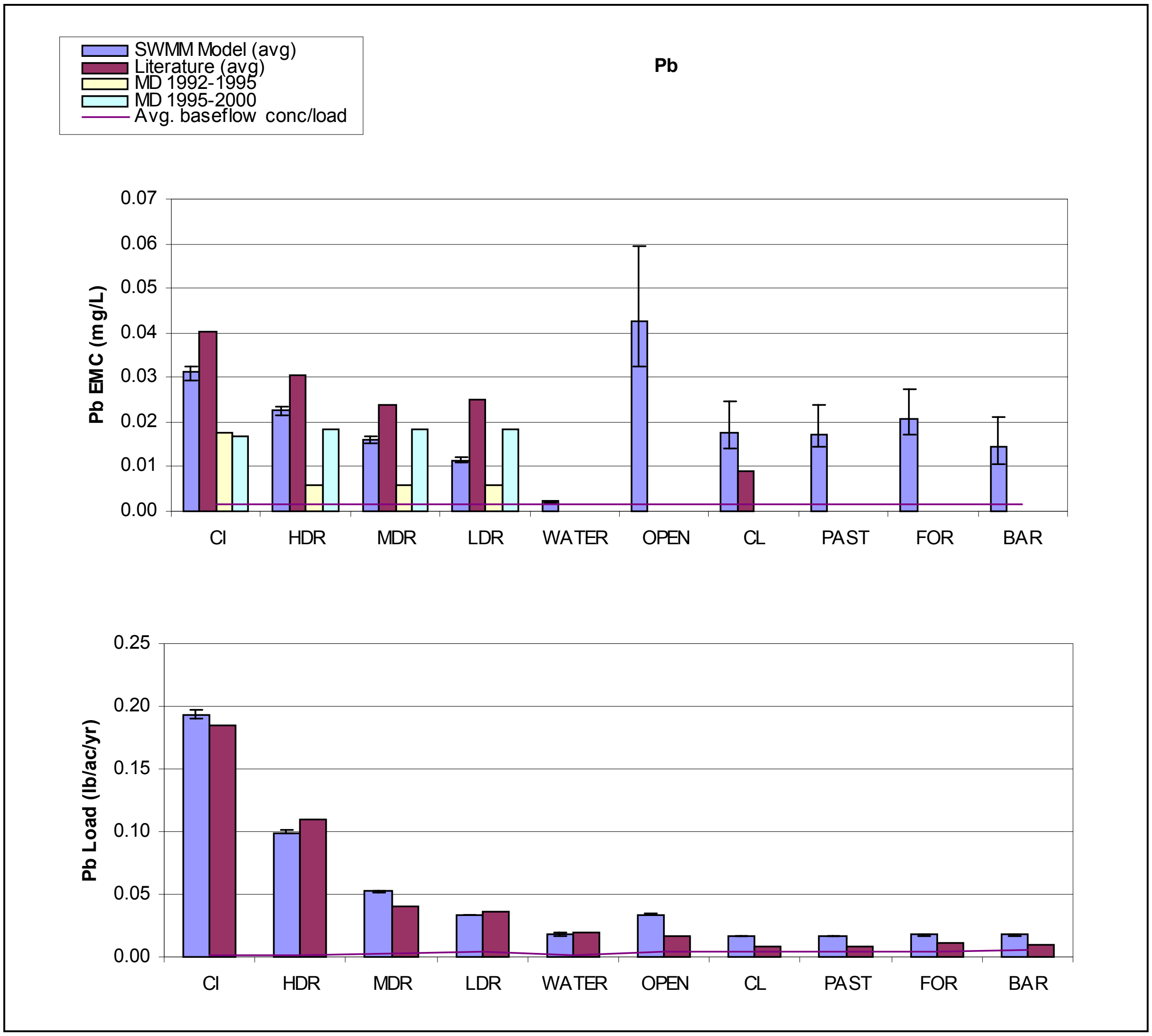

Figure 5.2.1-5: Pb EMC & Unit Load Comparison

A TSS concentration time series comparison for the Jones Falls Watershed at the Sorrento gauge location is displayed in Figures 5.2.2-1. TSS and Metals (Cu, Zn & Pb) concentration time series comparisons for Jones Falls Watershed at the downstream location are displayed in Figures 5.2.2-2 to 5.2.2-5. The remaining sub-watershed time series are displayed in Appendix J.

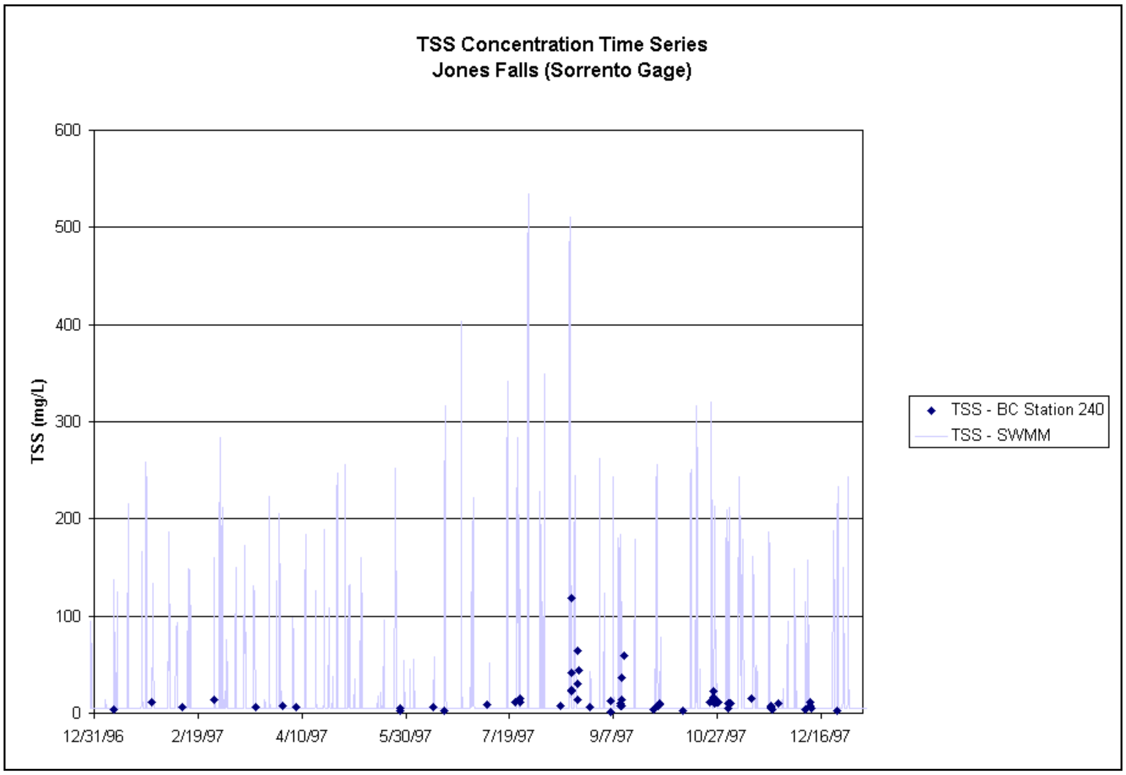

Figure 5.2.2-1: Jones Falls TSS Concentration Time Series (Sorrento USGS gauge)

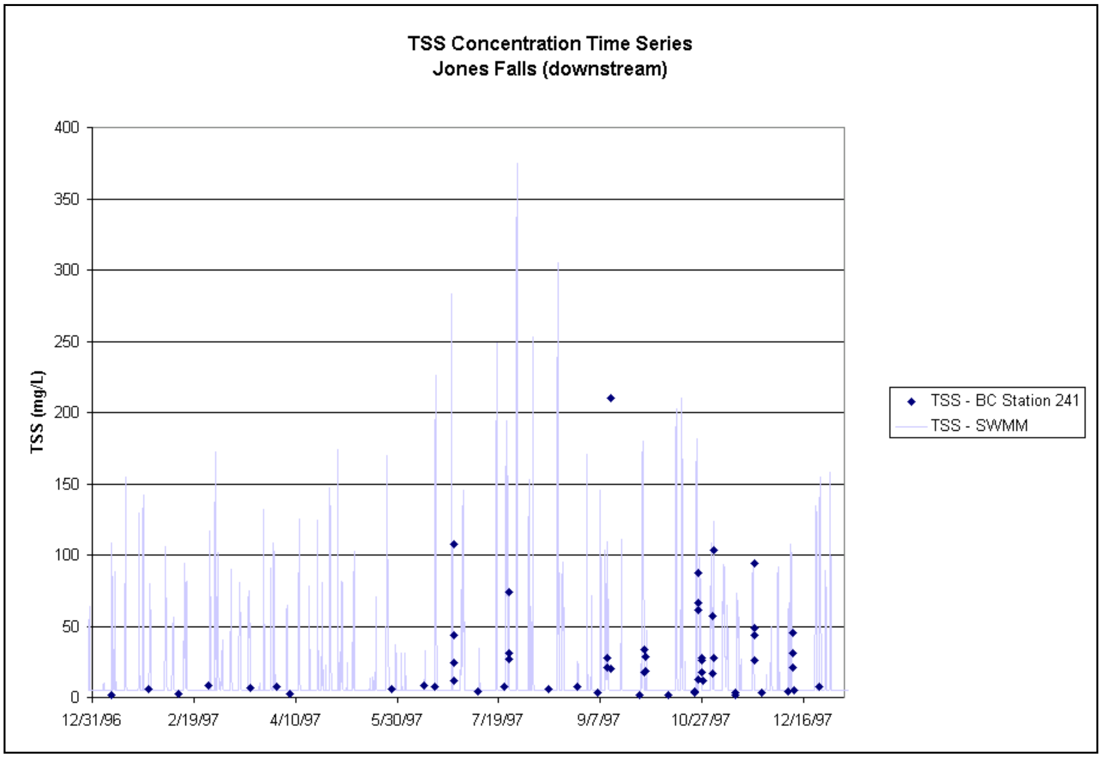

Figure 5.2.2-2: Jones Falls TSS Concentration Time Series (Downstream)

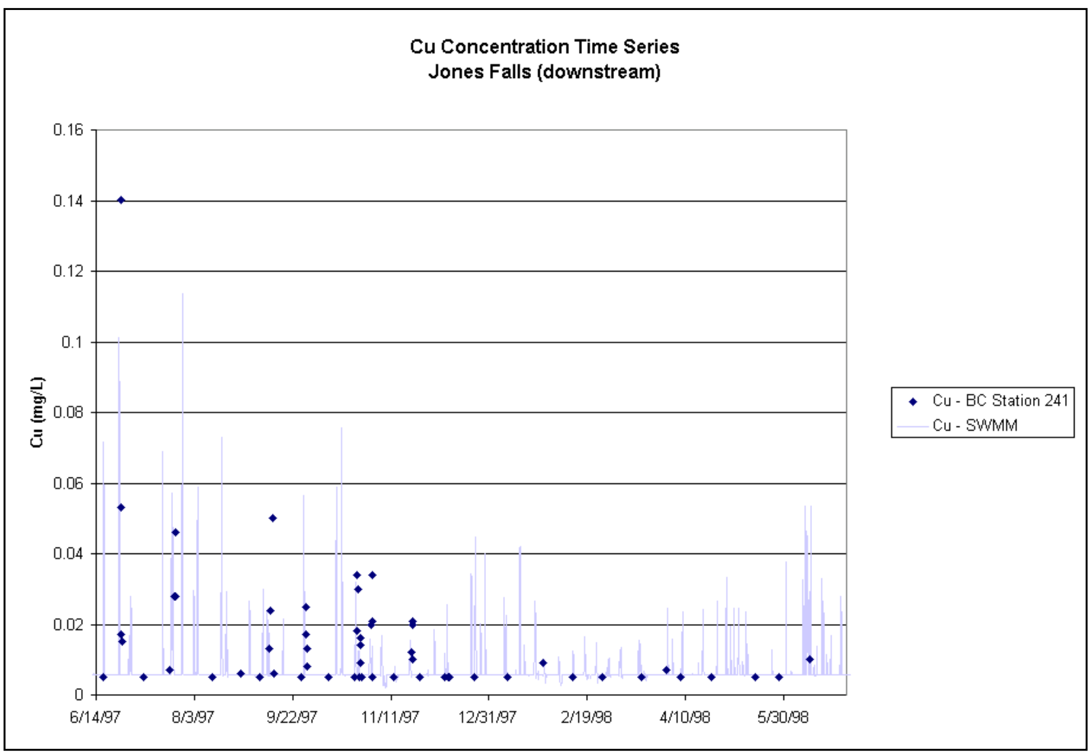

Figure 5.2.2-3: Jones Falls Cu Concentration Time Series (Downstream)

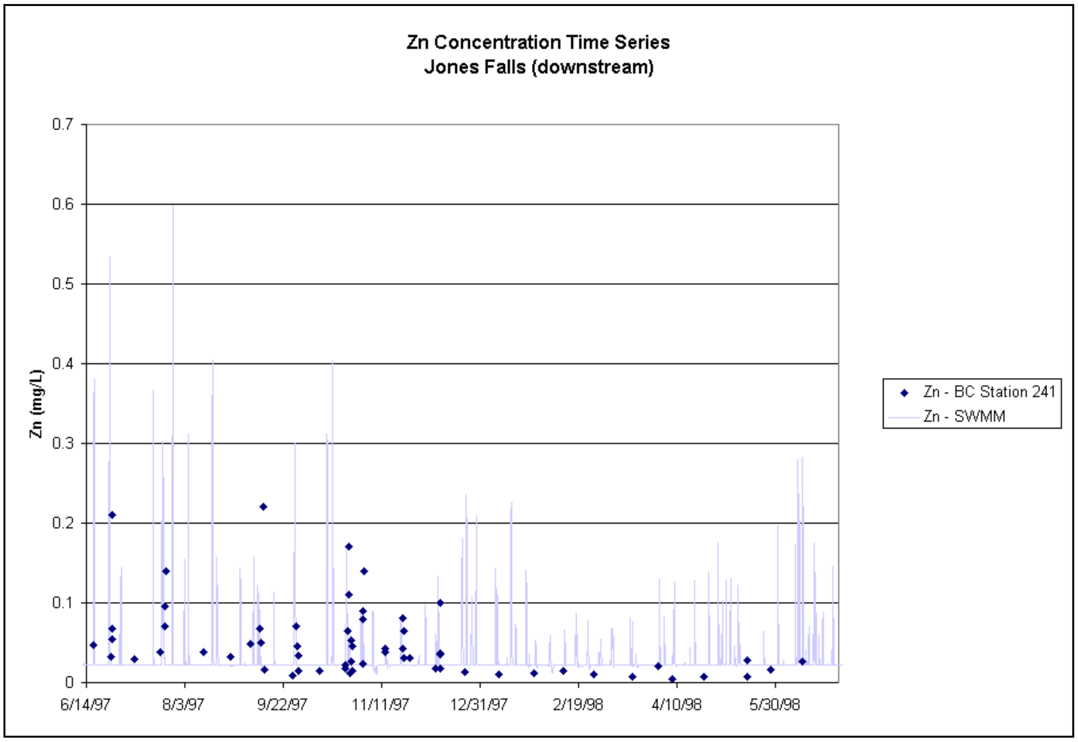

Figure 5.2.2-4: Jones Falls Zn Concentration Time Series (Downstream)

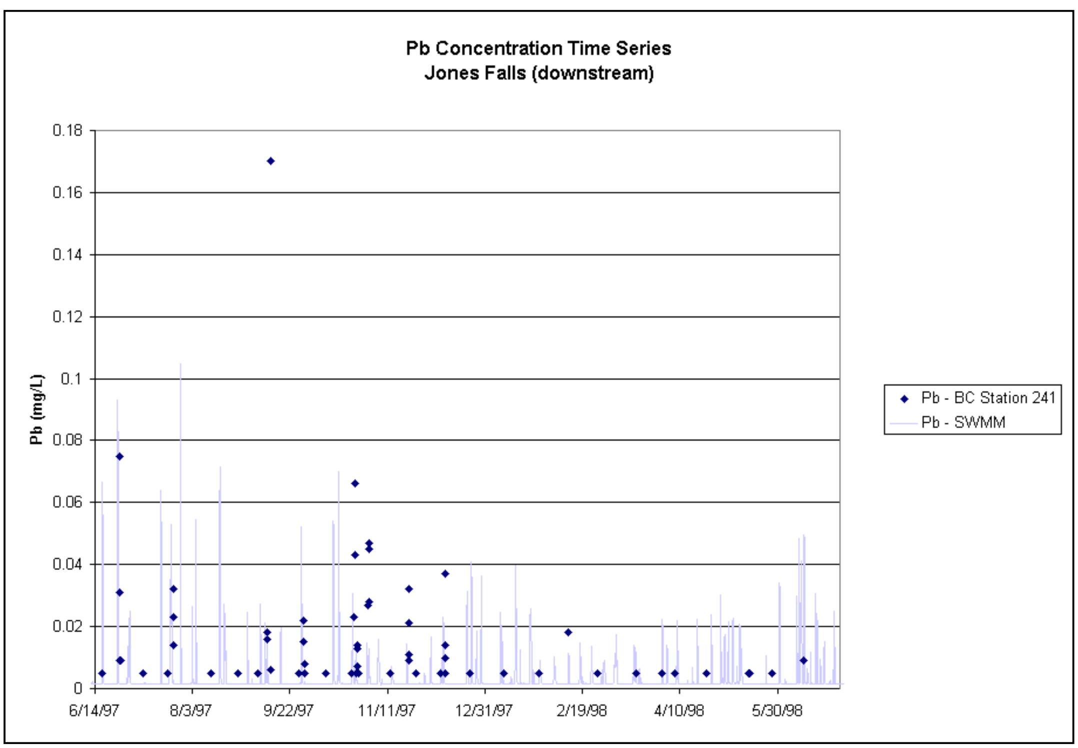

Figure 5.2.2-5: Jones Falls Pb Concentration Time Series (Downstream)

6 Patapsco/Back River Watershed Load Summary

The average annual delivered loads (1992 to 2000) from the five sub-watersheds are listed in Table 6-1 with the total watershed loads summarized at the bottom. Average annual unit loads are listed in table 6-2. Model results indicate that the largest delivered load for TSS is from the Patapsco River sub-watershed with the smallest TSS loads from the Back River and Jones Falls sub-watersheds. For the four metals, the largest sub-watershed source is from the area directly surrounding the Baltimore Harbor. With respect to average annual unit loads, Gwynns Falls has the highest unit load for TSS and the drainage area surrounding Baltimore Harbor has the highest unit load for all metals except copper. The highest unit load for copper occurs in the Gwynns Falls watershed.

Table 6-1: Patapsco/Back River Average Annual Loads (1992-2000)

Sub-Wateshed	Area (acres)	Flow (MG/yr)	TSS (ton/yr)	Cr (lb/yr)	Cu (lb/yr)	Zn (lb/yr)	Pb (lb/yr)
Back River	35,623	22,542	3,531	464	2,960	15,907	2,577
Baltimore Harbor	62,499	41,130	6,415	1,132	5,079	31,623	5,128
Gwynns Falls	40,329	24,851	4,495	529	3,537	15,797	2,826
Jones Falls	37,700	21,549	4,971	348	2,386	12,003	2,038
Patapsco River	130,634	71,335	25,205	961	5,312	25,963	4,841
Total	**306,785**	**181,408**	**44,617**	**3,433**	**19,273**	**101,292**	**17,411**

Table 6-2: Patapsco/Back River Average Annual Unit Loads (1992-2000)

Sub-Wateshed	Area (acres)	Flow (MG/acre/yr)	TSS (lb/acre/yr)	Cr (lb/acre/yr)	Cu (lb/acre/yr)	Zn (lb/acre/yr)	Pb (lb/acre/yr)
Back River	35,623	23.3	198.2	0.013	0.083	0.447	0.072
Baltimore Harbor	62,499	24.2	205.3	0.018	0.081	0.506	0.082
Gwynns Falls	40,329	22.7	222.9	0.013	0.088	0.392	0.070
Jones Falls	37,700	21.0	263.7	0.009	0.063	0.318	0.054
Patapsco River	130,634	20.1	385.9	0.007	0.041	0.199	0.037
Total	**306,785**	**21.8**	**290.9**	**0.011**	**0.063**	**0.330**	**0.057**

Table 6-3 lists the average annual base flow loads delivered to the harbor. These numbers indicates that base flow is most significant for copper, where the base flow load is 24% of the total load and least significant for TSS and lead, where the base flow contribution is approximately 7 to 8% of the total loads. Chromium and zinc base flow loads contributions are 17% and 12% respectively.

Table 6-3: Patapsco/Back River Average Annual Base Flow Loads (1992-2000)

Sub-Watershed	TSS (ton/yr)	Cr (lb/yr)	Cu (lb/yr)	Zn (lb/yr)	Pb (lb/yr)
Back River	174	37	441	2,269	129
Baltimore Harbor	289	85	919	2,535	211
Gwynns Falls	195	68	793	884	144
Jones Falls	198	56	507	1,650	139
Patapsco River	1,393	320	1,930	4,753	671
Total	**2,248**	**566**	**4,589**	**12,092**	**1,293**
% Base Load	**4.8%**	**16.5%**	**23.8%**	**11.9%**	**7.4%**

Tables 6-4 & 6-5 list the average annual load and load percentages by land use for the Patapsco/Back River watershed. The developed land uses account for over 44% of the TSS delivered to the Baltimore Harbor. For the four metals, developed land uses account for over 81%. The Patapsco River watershed accounts for the largest contribution of TSS due to its size. The Baltimore Harbor, containing the greatest area of developed land use, accounts for the largest contributions of Cr, Zn and Pb. The Patapsco River at over twice the land area of Baltimore Harbor contributes slightly more Cu.

Table 6-4: Patapsco/Back River Average Annual Loads by Land Use (1992–2000)

Landuse	TSS (tons/yr)	Cr (lb/yr)	Cu (lb/yr)	Zn (lb/yr)	Pb (lb/yr)
CI	7,515	2,120	4,613	48,817	7,411
HDR	3,849	268	4,208	14,392	2,829
MDR	5,793	486	5,852	19,690	3,460
LDR	2,352	205	963	7,402	1,069
WATER	31	2	112	102	61
OPEN	985	26	413	1,553	400
CL	15,823	87	906	2,882	547
PAST	2,904	25	271	821	154
FOR	5,157	209	1,887	5,475	1,443
BAR	207	5	48	158	36
Sum	**44,617**	**3,433**	**19,273**	**101,292**	**17,411**

Table 6-5: Patapsco/Back River Average Annual Load % by Land Use (1992-2000)

Landuse	TSS (tons/yr)	Cr (lb/yr)	Cu (lb/yr)	Zn (lb/yr)	Pb (lb/yr)
CI	17%	62%	24%	48%	43%
HDR	9%	8%	22%	14%	16%
MDR	13%	14%	30%	19%	20%
LDR	5%	6%	5%	7%	6%
Sum Urban	**44%**	**90%**	**81%**	**89%**	**85%**
WATER	0%	0%	1%	0%	0%
OPEN	2%	1%	2%	2%	2%
CL	35%	3%	5%	3%	3%
PAST	7%	1%	1%	1%	1%
FOR	12%	6%	10%	5%	8%
BAR	0%	0%	0%	0%	0%

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